[Un]ited States—
Fuel administration
Conservation of fuel in U.S.

# The Conservation of Fuel

in the

# United States

An outline for a proposed course of lectures in
Higher Educational Institutions
prepared for the

UNITED STATES
FUEL ADMINISTRATION

Washington, D. C.

By L. P. BRECKENRIDGE

New Haven, Connecticut
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NOTE.

*The Fuel Administration assumes no responsibility for any opinions on the economic questions discussed in these Lectures.*

# INTRODUCTION.

At the request of the United States Fuel Administration and Charles R. Van Hise, in charge of the general subject of Conservation, these lectures have been prepared for the higher educational institutions.

It is the purpose of the lectures to present the more important features of Fuel Conservation, particularly as they relate to the methods and principles involved in burning coal with economy, both in the homes and in the industries.

The material presented has been prepared with the hope that it might furnish a basis for a series of lectures to be presented by selected members of the staffs of the various scientific and technical schools throughout the country.

It is expected that the problems of fuel conservation of special importance to the interests of the several states or localities where the lectures are used will be more fully developed than has been attempted in the general presentation as herein given. Many institutions have valuable charts and slides which will serve to bring home the important features of the subject. These should be freely used.

All students should be supplied with copies of these lectures and urged to extend a knowledge of the principles of conservation as applied to using fuel with economy. In many places the student himself might well present suitable explanations and instructions to groups of firemen or to householders. Where this has been attempted, excellent results have been obtained. The instructions given in the lectures are simple and easily understood by any one responsible for the care or operation of coal burning furnaces.

In these lectures it has seemed best not to discuss to any great extent the conditions which have led to the great "fuel shortage" of 1917, nor the steps which have necessarily been taken to tide over the situation, but rather to adhere to the presentation of those fundamental principles of the economic use of fuels with which all technical students should be thoroughly familiar.

The writer wishes to acknowledge his indebtedness to a large number of authors and investigators for much material freely used in the preparation of these lectures. To the technical school graduate of the last fifteen years we are indebted for many important researches which have advanced the knowledge of economic fuel burning. The writer is proud of their work and urges them on to further study and investigation in this important field.

Additional copies of this bulletin may be obtained from the writer.

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Professor of Mechanical Engineering,
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New Haven, Connecticut,
February 25, 1918.

LECTURE I.

# FUELS

## THE IMPORTANCE OF FUELS.

The importance of fuel is recognized by everyone. The conditions imposed by the Great War have served to emphasize its need as never before. We have always needed fuel to cook our food and keep us warm. When we came to America, fuel was of one kind, wood, which was very plentiful, and bringing in the supply of wood was the task for the winter days. With skill the farmer felled the tree where he willed. The axe, the saw and the wedge prepared the fuel and the ox-sled furnished the transportation system. Had it not been for a single invention, the steam engine, doubtless our fuel problems would still be confined largely to the early methods of individual and neighborhood supply of peat and wood. How great has been the change! The work of the world must now be done by power and not by human hands, and for the production of power we have largely depended upon the burning of coal.

There are many other important uses for fuel besides cooking our food and keeping us warm; everyone easily thinks of such uses: Fuel lifts ores from the mines, reduces them to workable metals, and shapes them into many and varied useful shapes and forms. Fuel hauls passengers and freight over long distances on water and on land; for this service alone 150,000,000 tons of coal will be burned this year. Where water power is not easily available, fuel furnishes the great generators with electrical energy which flows through small copper threads in ever-increasing amounts, making power available in millions of homes, farms, cities and factories, always performing that greatest service—releasing human servitude. Fuel warms our homes, our public buildings and our factories by methods both convenient and sanitary, far surpassing the methods of fifty years ago. Fuel gives us light by oil, gas and electricity, and in no field of research has there been produced greater economies leading to conservation than in the field of lighting.

Considering the importance of fuel, is it not essential that we should all learn to use it in the best and most economical way, especially since once it is burned it cannot be replaced?

## CLASSIFICATION OF FUELS.

The sun is the source of all fuel. The heat from the sun has made vegetable and animal life possible on earth. While at times and at some

places a small amount of animal fat and oil was used for the production of heat and light, at present man depends almost entirely upon fuel of ancient vegetable origin. It is true that fuel may be produced in a single year if it be alcohol, bagasse or straw, or it may be produced in from 10 to 50 years if it be wood, but our great present supply was produced at least 6,000 years ago by conditions which at present do not exist.

Fuel is usually classified under three headings: (a) solid, (b) liquid, (c) gaseous, and under each of these headings we may have Natural Fuel and Prepared Fuel.

The solid fuels have progressed step by step from pure cellulose to anthracite, varying in composition about as shown in the following table:

TABLE 1.—COMPOSITION OF SOLID FUELS.[1]

| Substance. | Element and Symbol. | | |
|---|---|---|---|
| | Carbon (C). | Hydrogen (H). | Oxygen (O). |
| | *per cent.* | *per cent.* | *per cent.* |
| Pure cellulose | 44.44 | 6.17 | 49.39 |
| Wood | 52.65 | 5.25 | 42.16 |
| Peat | 59.57 | 5.96 | 34.47 |
| Lignite | 66.04 | 5.27 | 28.69 |
| Brown coal | 73.18 | 5.58 | 21.14 |
| Bituminous coal | 75.06 | 5.84 | 19.10 |
| Semi-bituminous coal | 89.29 | 5.05 | 6.66 |
| Anthracite coal | 91.58 | 3.96 | 4.46 |
| Graphite | 100.00 | .... | .... |

## THE CHARACTERISTICS OF AVAILABLE FUELS.

*Wood.*—Where wood is plentiful it is still used for fuel, but its use for making steam has almost ceased. We still use it in our fireplaces, as of old, but here it adds cheerfulness rather than much heat to the room.

The relative values of wood and coal as fuels are shown in Table 2. From these values it will be easy to calculate the comparative cost of supplying heat by burning either wood or coal.

*Peat.*—A Large number of peat bogs exist in the United States. It is of interest to note that the regions where peat is most abundant are frequently remote from the coal fields. The use of peat as a fuel has not as yet made much progress in the United States. With the increasing price of coal more attention may be given to the use of peat. In any proposed development, we shall find it wise to be governed by the experiences of those foreign countries that have been using this fuel for many years.

[1] Steam Power Plant Engineering, Gebhardt. John Wiley & Sons, N. Y., 1917.

TABLE 2. RELATIVE HEATING VALUES OF WOOD AND COAL.

| Kind of wood. | Weight per cord in pounds. | Heating value value B.t.u. per lb. | Equivalent wgt. of coal of 13500 B.t.u. |
|---|---|---|---|
| Ash | 3520 | 5450 | 1420 |
| Beech | 3250 | 5400 | 1300 |
| Birch | 2880 | 5580 | 1190 |
| Cherry | 3140 | 5420 | 1260 |
| Chestnut | 2350 | 5400 | 940 |
| Elm | 2350 | 5400 | 940 |
| Hemlock | 1220 | 6410 | 580 |
| Hickory | 4500 | 5400 | 1800 |
| Maple, Hard | 3310 | 5460 | 1340 |
| Oak, Live | 3850 | 5460 | 1560 |
| " White | 3850 | 5400 | 1540 |
| " Red | 3310 | 5460 | 1340 |
| Pine, White | 1920 | 6830 | 970 |
| " Yellow | 2130 | 6660 | 1050 |
| Popular | 2130 | 6660 | 1050 |
| Spruce | 1920 | 6830 | 970 |
| Walnut | 3310 | 5460 | 1340 |
| Willow | 1920 | 6830 | 970 |

A valuable bulletin[1] by Mr. Charles A. Davis reviews the subject of formation, preparation and utilization of peat, discussing its use not only for fuel but for many other purposes. It also contains a "Selected Bibliography on Peat" of some sixty references. From this bulletin the following extracts are made:

" Peat has long been generally used in Europe as fuel for heating and other domestic uses, and more recently for power generation. Its production in compacted forms suitable for transportation and storage is growing constantly, so that at present every European country having any considerable area of peat deposits is increasing the output of peat fuel.

" It must also be considered that any mechanical devices and processes for making peat fuel and other products which are in successful operation abroad are those which have established themselves by demonstrating through a long period of years their value in competition with many others which have been eliminated because of failure to meet the demands put upon them by the requirements of actual commercial operations. These devices and processes are therefore all the more worthy of careful study by prospective investors in this country.

" The foundation of all successful development and growth of peat industries in the United States must be a thorough scientific study of the occurrence, nature, qualities, and peculiarities of peat itself and a careful and honest investigation of the status of these industries in the European countries in which they have reached self-supporting existence. To begin without these preliminary studies would be the height of folly.

" Comparing the cost of peat fuel with that of coal, the former could be produced with less danger and with a much less expensive equipment if it needed only to be dug, because it lies at or just below the surface of the ground.

[1] The Uses of Peat, by Charles A. Davis, Bureau of Mines, Washington, D. C.

A readily marketable type of peat fuel, in the form of air-dried, slightly compressed blocks, can probably be produced at an expense of from 75 cents to $1.25 or $1.50[1] per ton, and, with properly devised and properly arranged machinery, production on a large scale would considerably lower the higher price for peat of well-decomposed types.

"No peat fuel has yet been produced at such low cost in this country, however, and that the figures based upon European production can be made the basis of calculation for American conditions remains to be demonstrated. That the bulkiness of air-dried peat fuel will make the cost of transportation and of storage under cover relatively high must also be noted. The high cost of transportation will probably prevent the shipment of the product for any considerable distance from the place of origin except by water routes; the high cost of storage will easily adjust itself when consumers have an opportunity to learn the value of peat fuel.

"Both transportation and storage are facilitated and objections of the sort mentioned are reduced to a minimum if the peat is compacted by thorough maceration, or pressed into small, dense, compact briquets by the use of powerful briquetting presses.

"Peat is found in all parts of the earth where the conditions of moisture are favorable, but it is most uniformly present in regions where the rainfall is regular and abundant and the relative humidity of the air is constantly high. The first factor supplies the necessary water, and the second prevents excessive evaporation. As cool or cold air is much more readily saturated with water vapor than is warm air, the temperate and cold parts of the earth generally have more humid atmosphere than the warmer parts, and in this respect are favorable to peat formation."

Peat has a heating value about one-half that of coal, but varying greatly. The bulletin above referred to gives the complete analysis of several hundred samples from a dozen or more states.

The total area of the peat bogs of the United States has been estimated as approximately 12,000 sq. mi. Assuming a depth of 10 ft. and an average yield of 200 tons per acre for each foot of depth, the total supply would reach 15,360,000,000 tons. This would be sufficient to take the place of our present yearly rate of anthracite production for about 70 years

It is evident that peat as a fuel cannot be seriously considered for some time and then only locally in the region where it is plentiful and near a market.

Peat has been used successfully in gas producers,[2] and perhaps it may finally be found cheaper to convert its energy into electricity, which is easily distributed, rather than attempt to distribute the somewhat bulky peat itself.

*Petroleum.*—In the year 1859, when Colonel Drake discovered crude petroleum in the northwestern part of Pennsylvania, the production

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[1] These were 1911 prices.

[2] Résumé of Gas Producer Investigations, by R. H. Fernald and C. P. Smith. Bureau of Mines, Bulletin 13, Washington, D. C., 1911.

was 2,000 bbl. In the next year the production was 500,000 bbl. of 42 gal. each.

Since this early discovery, oil has been produced in 16 states, and the total amount produced has continued to increase until the production in the United States in 1917 reached a total of 344,000,000 bbl.

A study of the available statistics reveals the fact that in every oil-producing state except California the production has begun to decrease, and in the states where its use was begun early, the yearly production has fallen off very much. As illustrating this decrease in production it may be noted that while the yield of the Pennsylvania-New York district in 1891 was 33,000,000 bbl., it had fallen off in 1912 to 8,700,000 bbl. In Ohio the yield of 1896 was 24,000,000 bbl., while in 1912 it was but 8,500,000 bbl. It has been the same for other states and except for a very extended search for new fields our supply would have long since been practically exhausted.

The discovery of oil on the Pacific Coast was a factor of much importance to our Navy, making oil available for its use in that region. Although continued search for oil is in progress, at the present time fully 65 per cent. of the world's supply comes from the United States, about 15 per cent. from Russia and 10 per cent. from Mexico. The development of the Mexican oil fields, while checked for the time being, is making important progress. One district alone comprises 10,000 square miles, rich in crude oil.

While oil cannot displace coal to any great extent as a fuel, there will always be some localities where it may be burned economically. It is an excellent fuel. It is burned under steam boilers with a high efficiency, 80 to 85 per cent. being attained, which is fully 10 per cent. better than the best practice in burning coal.

The heating value of oil is considerably higher than coal for equal weights. A barrel of oil of 42 gal. weighs from 310 to 350 lb., according to its specific gravity.

Compared with coal, oil occupies about 50 per cent. less space and is 35 per cent. less in weight for equal heat values.

The following table[1] gives the comparative heat values of coal and oil.

| B.t.u. per pound of coal | Pounds of coal equal to 1 barrel of oil | Barrels of oil equal to 1 short ton of coal |
|---|---|---|
| 10,000 | 620 | 3.23 |
| 11,000 | 564 | 3.55 |
| 12,000 | 517 | 3.87 |
| 13,000 | 477 | 4.19 |
| 14,000 | 443 | 4.52 |
| 15,000 | 413 | 4.84 |

[1] Steam Power Plant Engineering, Gebhardt. John Wiley and Sons, N. Y., 1917.

*Natural Gas.*—This is an ideal fuel, it has all the advantages and but few of the disadvantages of other fuels. Unfortunately it is not available except in some favored localities and the supply, like oil, has gradually diminished in most places where it has been freely used. Difficulties attending the control of its production and distribution brought about enormous wastes in the early years of its discovery.

The approximate consumption of natural gas during the 10-year period from 1906-1915 is as follows:

| Year. | Billion cu. ft. |
|---|---|
| 1906 | 389 |
| 1907 | 410 |
| 1908 | 405 |
| 1909 | 485 |
| 1910 | 510 |
| 1911 | 515 |
| 1912 | 565 |
| 1913 | 583 |
| 1914 | 592 |
| 1915 | 629 |

The value of the 1915 production was estimated at $101,303,000, which is 470 times the value of the production of 1882.

The 1915 production was consumed by two million customers for domestic use and eighteen thousand customers for industrial purposes, the former using 34.5 per cent., the latter 65.5 per cent. of the production.

Natural gas is composed largely of marsh gas ($CH_4$) and hydrogen (H), and its heating value is approximately 850 B.t.u. per cu. ft. If we assume 15 cu. ft. of gas as the equivalent of one pound of coal (850 x 15 = 12,750 B.t.u.) it will be seen that the total 1915 production of natural gas would have a heating value equal to 21,000,000 tons of coal, about one-fifth the anthracite production.

The demand for gasolene has resulted in the perfection of the processes of extraction of gasolene from the natural gas of oil wells and this production has been rapidly increasing. It was 7,425,000 gal. in 1911[1] and increased to 65,365,000 gal. in 1915.

Natural gas can be used very advantageously in many industrial processes for which coal is not desirable. It would almost seem as though its use might well be restricted to the special purposes for which it is best adapted and not used simply to replace coal for heating or power purposes.

*Coal.*—Coal is by far the fuel of greatest importance. Fortunately, it exists in large quantities in the United States. It is also distributed over wide areas. The facilities for mining coal have been wonderfully improved and developed during the last quarter of a century. We began the mining of coal in the United States very early in the nineteenth

[1] Mineral Production of the United States in 1915, U. S. G. S.

century. The amount of coal mined was at first very small, about one million tons in 1836, but increased continually during the succeeding years until at present the amount produced in the United States, 640 million tons in 1917, far exceeds that produced in any other country.

The United States has now entered into competition with the world as a manufacturing nation. It is fortunate indeed that there exist such large resources available for the production of power in the coal mines of the United States. With coal as a fuel we may produce power with great economy and the use of power will enable us to displace human energy and produce our manufactured products at a minimum cost.

It is extremely important that we stop wasting coal. While our supply is enormous it is by no means unlimited. Suitable equipment is now available for burning coal with economy. Are we not criminally negligent if we do not use it?

When we waste coal we not only destroy the coal itself but we waste the labor of mining it as well as the cost of transporting it from the mine to the factory or home.

The lectures which follow take up in detail the considerations involved in the economical use of coal for commercial and domestic purposes.

LECTURE II.

# THE PRODUCTION, DISTRIBUTION AND USE OF COAL.

## PRODUCTION.

During the year 1917, the United States has produced 640,000,000 tons of coal. This is an increase of 8 per cent. over the preceding year, and 21 per cent. over the year 1915. It is a much larger amount than has been produced in a single year by any other nation. It is difficult to comprehend the magnitude of this production.

The mining of coal began in this country about 1807, and the amount mined during the past year is approximately equal to the entire amount mined during the first 65 years of the coal industry of this country. Nevertheless, in spite of its magnitude, this great production has fallen far short of the nation's needs. Not only have we been obliged to practice "strict economy" in the use of coal, but we have been obliged to omit its use altogether for many purposes which we have formerly considered necessary. The difficulty has been not one of mining coal, but of distribution to the consumer.

In the United States there are 7,000 coal mines and 70,000 miners. Coal is not mined unless there are cars into which it may be loaded. If cars are not available, the coal is not mined, and the miners are idle. In 1915 the 5,600 bituminous mines of the country were operated only 203 days, producing therefore but two-thirds as much coal as might have been produced. It is a fact that coal can be taken out of the mine and loaded on cars more rapidly than it can be loaded from a surface supply mined in advance. All the machinery of mining, hoisting, sizing and loading is arranged for this method of operation. It is less expensive to handle in this way.

The difficulties of transportation have been due to many reasons, and it cannot be said that failure to provide transportation has been due entirely to the railroads, as they have worked in harmony with the mines as far as existing laws would permit, and actually have carried more freight than ever before in their history.

Some of the many reasons why the railroads have not been able to handle expeditiously the freight offered are as follows: (a) lack of centralized authority, (b) tremendous increase in the demands of the industries, (c) insufficient equipment, (d) lack of terminal facilities, (e) failure of consignees promptly to load and unload the cars, (f) lack of facilities for water transportation.

When the President announced in his order of December 26, 1917, that the railroads would be operated under government control by

William G. McAdoo, Director General of Railroads, both the public and the railroads were in sympathy with the proposed plan. Government control provided for two extremely important essentials: (a) centralized authority, and (b) sufficient money to maintain or extend existing facilities.

## THE DISTRIBUTION OF COAL.

It is not generally known that coal constitutes 35 per cent. of the weight of all the freight carried by the railroads but such is the case and in the eastern district, where the industries are many and the winters are severe, the coal amounts to 43 per cent. of the freight carried. The weight of the agricultural products moved by rail is about one-third the weight of coal. It will be evident that the conservation of coal becomes a matter of prime importance not only because we should not unnecessarily waste our coal resources but also because of the expense of hauling and distributing it.

It is for these reasons, briefly outlined, that it has seemed desirable to present in this lecture, some of the important statistics relating to the production and distribution of coal. Fortunately this material is now available in a recent publication of the United States Geological Survey,[1] and from this source many of the tables and charts of this lecture have been prepared. These will be presented and briefly described a little later.

Early in the summer of 1917, the United States Chamber of Commerce, of Washington, D. C., began a campaign of "Coal Conservation," and a bulletin was issued on August 27, 1917. At the request of the Council of National Defense, the Chamber appointed a "Committee on Coal Conservation." This Committee, of which Mr. Ernest T. Trigg, of Philadelphia, was Chairman, invited the American Society of Mechanical Engineers to designate three of its members to serve with the Committee. The appointment was made by the President of the Society. The material published in the bulletins of this Committee has been widely distributed to more than 900 cities, and much of it has been used to advantage in the local newspapers. The writer, a member of the Committee, has quoted freely from these bulletins more especially in this lecture. The following is from Bulletin No. 1, "The Situation."

"More coal is used in the United States than any other one material. No other supply is of such general importance to the industries of the country. The cost of coal to one business may be but a fraction of one per cent. of the enterprise's total cost of operation; it may to-day constitute as much as 90 per cent. of the costs of a public utility that develops and sells power; whatever the proportion of operation costs, coal is essential.

[1] Coal in 1915; Part A, Production; Part B, Distribution and Consumption; by C. E. Lesher, U. S. G. S., Washington, D. C.

Some users of coal have spared no effort or expense in obtaining efficiency in development of power from coal. Numerically, they are in the minority. Such users can contribute to the common good by making generally available some of their experience. Some other persons may have on hand supplies adequate for their needs in the immediate future; by avoiding waste they can extend the period during which their stocks will suffice and also can set an example. Every man who has to seek coal for his immediate requirements can see a direct personal advantage in economy.

" The highest possible degree of efficiency from the use of coal with existing equipment is the need of the moment. Conditions do not permit any general installation of new power-making or power-using plants. There will be an immense aggregate of saving in fuel consumed, of transportation capacity released for other articles, and of productive effort made available in other directions if all users of coal will see to it that their existing plants obtain from their fuel all the heat and power of which they are capable.

" Prevention of waste in fuel requires local attention. It will often involve diverse elements in different communities. Nevertheless, many suggestions of general applicability are possible. Such suggestions this Committee proposes sending you in a series of short, terse statements."

## THE USE OF FUEL.

Different localities use different kinds of fuel. It is extremely important that the lessons now being learned should not be forgotten and that definite plans should be made which will lead to a permanent economy in the use of fuel. This can be done by adopting types of equipment suitable to the fuels burned and by the use of correct methods of firing and operation. The following graphical charts, relating to the production, the distribution and the use of coal, require little explanation. It is believed that a study of these charts will be helpful in connection with the presentation of the facts which may be learned by a study of them. Many other very excellent charts may easily be prepared which will bring out facts of especial value and interest to certain localities. A few comments are added under each chart but many other points will occur to any who may use the material of these lectures as the basis of a presentation of the subject of fuel conservation.

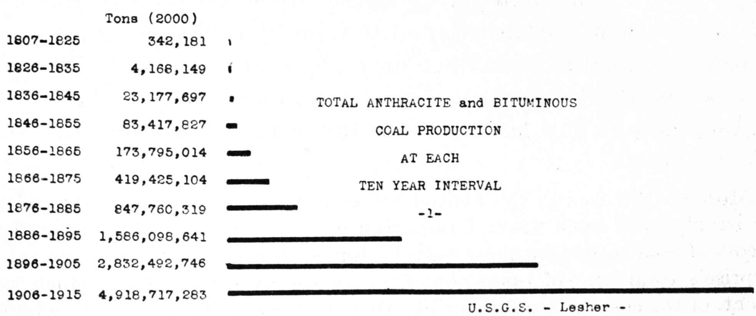


Chart 1.

The rapidly increasing rate of production as shown in this chart cannot long be kept up. If it is, our supply of coal will be gone long

before that of other nations having, at present, a smaller supply, but using it with the best known economy.

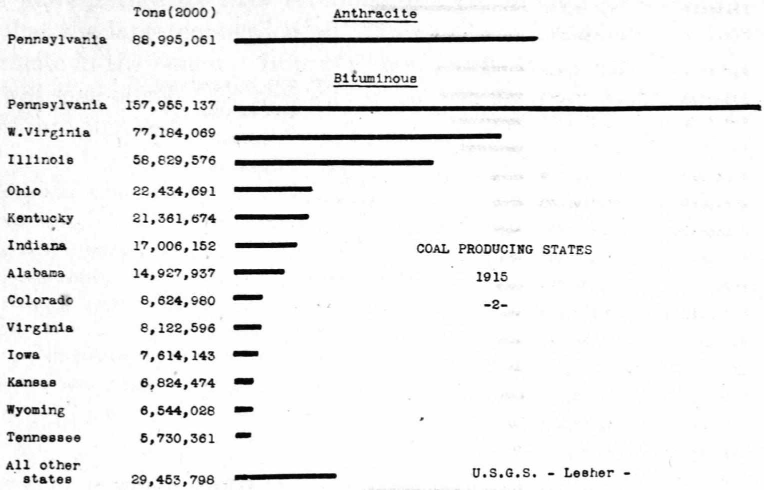


Chart 2.

Although coal is widely distributed, it requires the expenditure of vast sums for its transportation. Three states, Pennsylvania, West Virginia and Illinois now produce about 72 per cent. of our coal. The comparatively small amount of anthracite (16 per cent.) is to be noted. In 1917, the anthracite production amounted to about 98,000,000 tons, equal to 15.3 per cent. of the total coal mined.

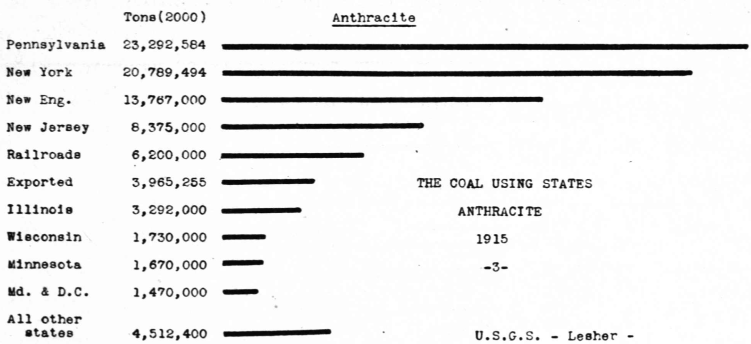


Chart 3.

Anthracite coal is largely used near the region of production. Considering its importance for some specific purposes, should not its use be discouraged where bituminous coal can be used in its place? Of the total unmined reserve coal in the United States certainly not more than 5 per cent. is anthracite. Should not this coal be largely reserved for household use?

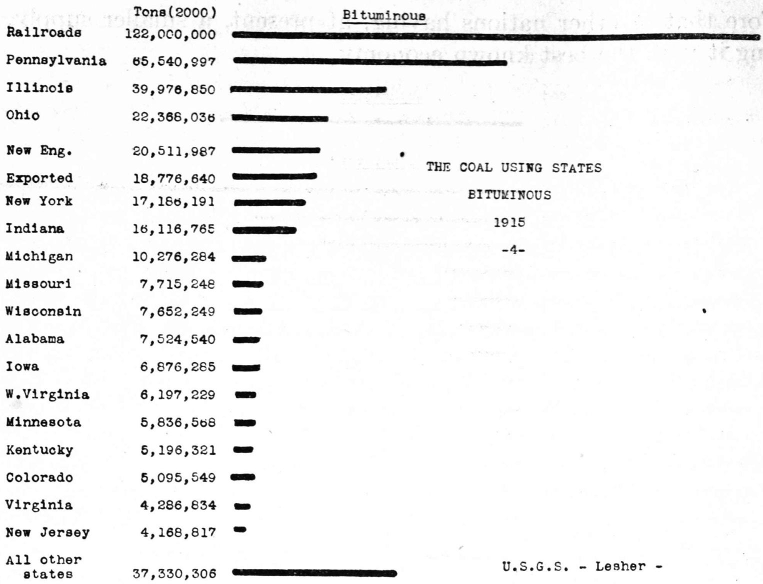


Chart 4.

What a price we pay for our vast extent of territory in the amount of coal used for the transportation of passengers and freight. It is estimated that in 1917 the railroads used 150,000,000 tons of coal. Just what part of this was used to haul *coal* it is difficult to estimate; possibly 35,000,000 tons. This is the estimated amount of coal used in 1917 by all public utility companies in the United States.

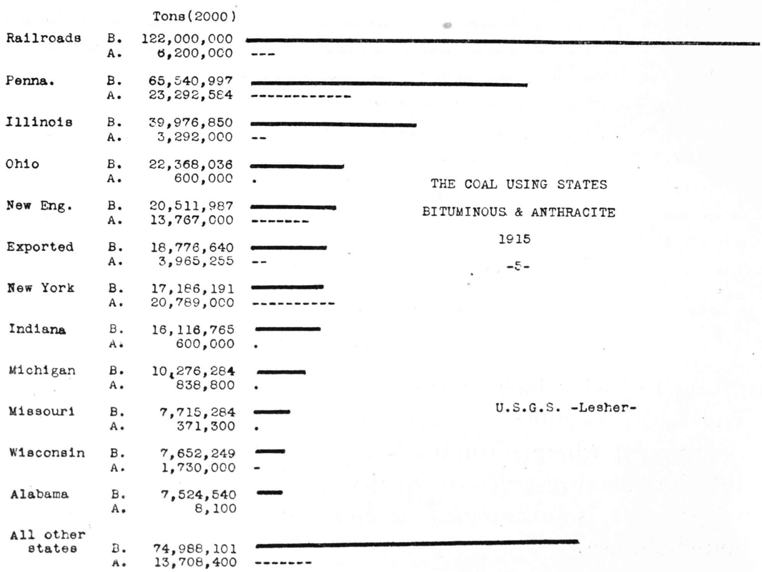


Chart 5.

The use of anthracite is apparently small compared with the use of bituminous. New York and New Jersey are the only states at present using more anthracite than bituminous. This is doubtless due to the fact that the large population of "Greater New York" requires much anthracite in the homes. Improved equipment for burning bituminous coal will soon obviate the necessity of hauling anthracite over long distances into the west.

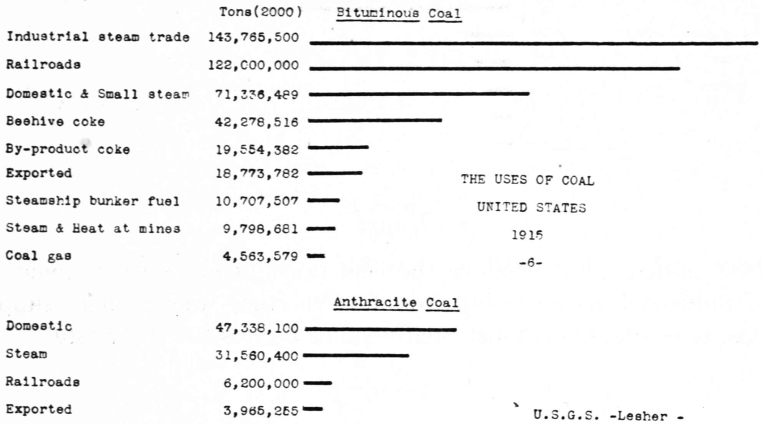


Chart 6.

This is a chart deserving of careful study. If we are to save coal, we must know the general uses of coal before we suggest our points of attack. Future statistics will doubtless be able to subdivide several of these items. But the possibilities of large immediate savings are not so evident when we examine the specific uses of coal. Questions will arise concerning the use of one-third the anthracite coal for steam purposes. Cannot this be saved for domestic use? Cannot the railroads give up their 6 millions, or more?

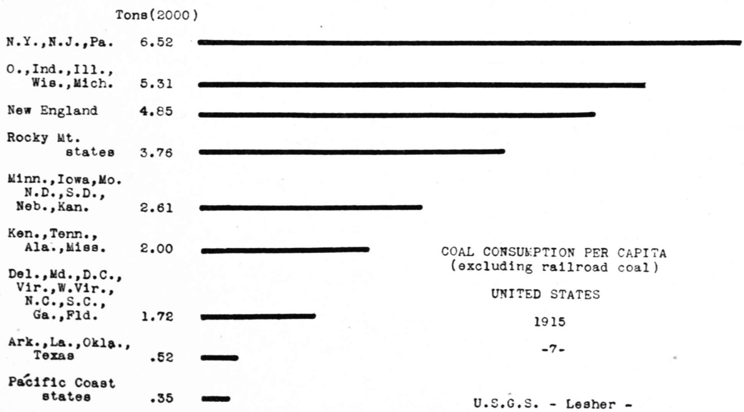


Chart 7.

An examination of this chart will reveal the great manufacturing states. The coal used for producing coke in Pennsylvania and Illinois accounts for the increased production of the groups containing those states. The effect of warmer climate is also to be noted.

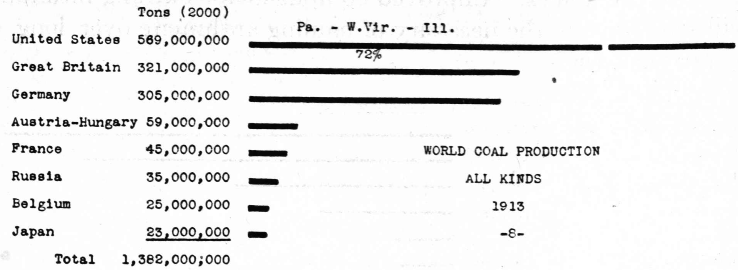


Chart 8.

Those nations that produce the coal must of necessity become the great industrial nations, but the nations that waste their supply, because it is abundant, must finally suffer because of the waste.

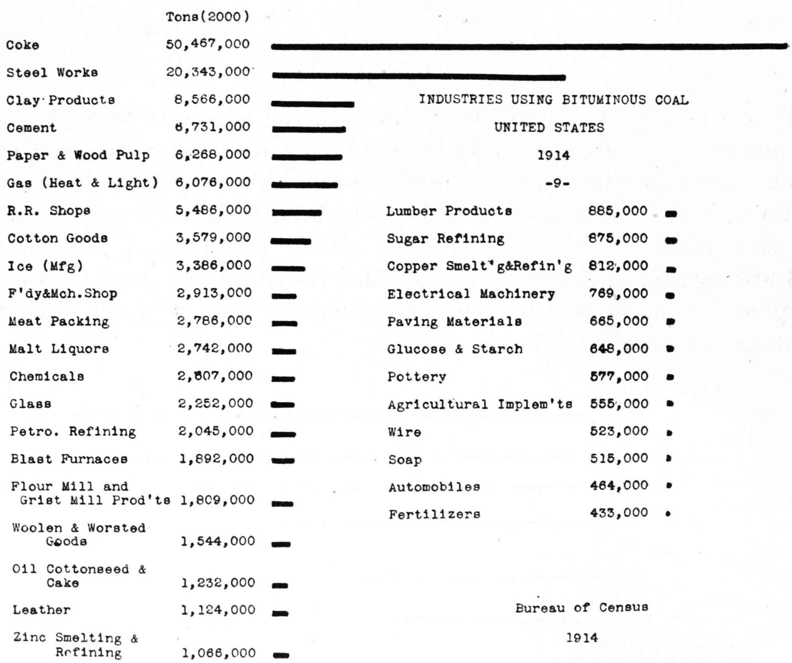


Chart 9.

The figures for this chart were obtained from the Bureau of the Census (1914). It contains valuable and interesting comparisons. Such a chart must be of considerable value in any consideration of coal restrictions to industries. It will be admitted that some of the figures are surprising. Even in 1914 few of us supposed that more coal was used in soap making than in the building of automobiles. It is interesting to note the considerable number of industries that would have to be closed for a year to save 50,000,000 tons of coal.

## THE PRESENT SHORTAGE.

The Seventh Annual Review number of "Coal Age" (Jan. 19, 1918) contains much valuable information upon the subject presented in this lecture. It is evident that the fuel shortage of 1917 was not due to exports as has sometimes been claimed. The increased production of 1917 over 1916 was about 45,000,000 tons. This increase was largely taken up (a) by the railroads, 16,000,000 tons, (b), by general industries, 20,000,000 tons, (c) by the government and (d) by the manufacturer of coke, 3,000,000 tons.

The demand of 1917 was evidently for 675,000,000 tons and the amount short of this demand (30,000,000 tons) has been met by drawing on the 1916 reserves for 3,000,000 or 4,000,000 and the rest by economies and enforced restrictions which fell most heavily upon the industries.

It is to be hoped that the production and distribution of 1918 will reach 800,000,000 tons. The mines can produce it. Will the railroads be able to haul it? In the meantime let definite steps be taken to use coal with careful economy, and let the lessons of 1917 result in a more careful study of the methods of conservation of our most wonderful and valuable natural resource—COAL.

LECTURE III.

# THE PRINCIPLES OF COMBUSTION.

## PROPER COMBUSTION ESSENTIAL FOR CONSERVATION.

Fully one-fifth of the coal now burned in the United States could be saved each year by adopting more economical types of furnaces in the home and factory and by operating these furnaces in accordance with well understood methods, avoiding at the same time the waste of coal which occurs when steam is thrown away or is not used economically in the generation of power.

The problem of saving 100,000,000 tons of coal, worth from $3.00 to $5.00 a ton, is one of so much importance that it demands the most careful attention. We have used our fuel supplies lavishly. Until recently, there has seemed to be plenty of wood and coal. We have been enjoying the results of burning fuel and have given too little thought to the process of burning it. The problems of combustion have been referred to the chemist or the engineer only recently, and the demand for increased power has been met by a greater consumption of coal, irrespective of economy.

The principles of combustion must be studied and more widely understood. The time has come when we are having our first real lessons in the crime of wastefulness, and fuel is one of this nation's resources which we must learn not to waste. When we consider the importance as well as the wide use of fuel, also the very great number of people directly concerned in using it, we are surprised at the great lack of a clear understanding of at least the elementary processes of combustion.

## COMBUSTION OF COAL DEFINED.

It is encouraging to see that a number of writers are appearing who are presenting the subject of combustion in a simple manner. More of such writers are needed. One of our recent clear, technical writers on the subject of the combustion of coal is Mr. Henry Kreisinger of the Bureau of Mines. He says:[1]

> "Combustion of coal is a chemical combination of the combustible ingredients of the coal with the oxygen of the air. The chief combustible ingredients of coal of economic importance are carbon and hydrogen in various combinations. Average commercial coal contains about 82 per cent. of carbon and about 4 per cent. of hydrogen available for combustion. Air, without which the coal could not burn, contains approximately 20 per cent. of oxygen and 80 per cent. of nitrogen."

This definition will bear careful reading. It avoids reference to non-essentials. It is a good starting point from which to attack the subject

[1] Combustion in the Fuel Bed of Hand Fired Furnaces, by Kreisinger, Ovitz, Augustine Technical Paper No. 137, Bureau of Mines, Washington, D. C.

and it is the intention of the writer to try to follow, as far as possible, the same simple presentation in this lecture.

## NEW TERMS: "HEAT UNITS"—"HEATING VALUES."

It will be observed when we begin to talk about the subject of combustion that there are a few new words and phrases with which we must become familiar. For instance, we must know what a "heat unit" is, and we must understand that different fuels will have different "heating values," and that the different fuels are composed of several elementary combustible substances, such as carbon, hydrogen, sulphur, often combined with other substances which cannot be burned such as moisture and ash.

Before proceeding further it might be well to explain that a "heat unit" is the amount of heat required to heat (raise the temperature of) a pound of water one degree, and is known as a British thermal unit, or B.t.u. Some good coals have a "heating value" of 14,000 B.t.u. per pound, which means that each pound of coal, if perfectly burned, would give up enough heat to raise the temperature of 7 tons (14,000 lb.) of water one degree on the fahrenheit scale.

It is a matter of much importance to know the heating values of the different coals and other fuels. These values are best exhibited and compared by means of a table and this is done in Table 1 which follows:

TABLE 1. APPROXIMATE HEATING VALUES OF DIFFERENT COALS.

| Fuel. | Heating values B.t.u. per pound. |
|---|---|
| | (varies) |
| Wood (dry) | 5500–7500 |
| Peat (air dried) | about–7500 |
| Lignite | 5200–7500 |
| Bituminous Coal | 9500–14500 |
| Anthracite Coal | 11500–14000 |
| Straw | about–5100 |
| Corn | 7200–8200 |
| Tanbark (dry) | about–6100 |
| Hydrogen | 62000 |
| Crude oil | 17500–21000 |
| Kerosene | 0.863 Sp.G.–18700 |
| Gasoline | 0.710 Sp.G.–18500 |
| Natural Gas | about 850 per cu. ft. |
| Producer Gas | " 125 " " " |
| Blast Furnace Gas | " 95 " " " |

Tables like the above enable us to know in advance just what is the largest possible amount of heat which can be obtained from the perfect (" complete," the chemist says) combustion of one pound (or one cubic foot, if it be a gas) of any fuel. The chemist has an instrument

called a calorimeter, in which he actually burns weighed samples of coal, with a known amount of oxygen. The burning takes place in a metal " bomb " under water and by measuring the temperature rise of the water, he thus determines accurately the heating value of the coal.

It may be a matter of surprise to some that all fuels appear to be composed almost entirely of the same elements, carbon and hydrogen. These two elements seem to delight in combining in many different ways. One combination is called, "marsh gas," and is given a symbol $CH_4$, which indicates that one atom of carbon has combined with four atoms of hydrogen. There are numerous other combinations having less easily remembered names but if we just call them all hydrocarbon gases it will be sufficient to identify them.

## PRODUCT AND HEAT OF COMBUSTION.

We might very well define combustion as a rapid chemical combination resulting in heat and light. The combining elements are carbon or hydrogen from the fuel and oxygen derived from the air.

A small amount of sulphur sometimes occurs in fuel and it also combines with oxygen, but sulphur is an undesirable element and it is eliminated as much as possible from burning fuels.

All of the elements in fuel that will combine with oxygen are called the " combustible materials," the escaping gases produced by this combination are called the " product of combustion," and the heat that is produced by burning one pound of the fuel is called the "heat of combustion." This heat is measured in British thermal units (B.t.u.), called shortly, a " heat unit," as already defined.

If we wish to burn fuel with economy we must arrange our fuel burning devices so as to provide for mixing the correct amount of the carbon and the hydrogen of the fuel, with the right amount of oxygen, taken from the air, and this mixture can not be accomplished unless the combination takes place at a sufficiently high temperature, called the " ignition temperature."

In Table 2 are shown both the product and the heat of combustion of the three elements which are usually found in the fuels which we are accustomed to burn.

TABLE 2. COMPLETE COMBUSTION OF THREE ELEMENTS.

| Combustible elements and symbol. | Product of combustion and symbol. | Heat of combustion B.t.u. per lb. |
|---|---|---|
| Hydrogen—H.......... | Water............$H_2O$ | 62000 |
| Carbon —C........... | Carbon dioxide....$CO_2$ | 14500 |
| Carbon —C........... | Carbon monoxide..CO | 4400 |
| Sulphur —S........... | Sulphur dioxide...$SO_2$ | 4000 |

It will be observed that the complete combustion of the above three elements consists simply in the proper union of these elements with oxygen. Two atoms of hydrogen combined with one of oxygen and the heat of combustion, 62,000 B.t.u., is very high. Carbon may combine with either one or two atoms of oxygen, and it should be noted carefully that the heat of combustion is much higher when it combines with two atoms rather than one atom.

It is very essential that furnaces burning coal should provide for the supply and regulation of the air supply in such a manner as will bring about the combination of two atoms of oxygen with each atom of carbon. If this is not done the combustion is said to be incomplete and much less heat will be made available, while the loss of heat up the chimney will be considerable.

A knowledge of the relative weights of the elementary atoms gives a direct means of computing the amount of oxygen required for combustion, and this in turn suffices to determine the amount of air required.

Hydrogen is the lightest of all the elements; compared with it the weights of the gases entering into the combustion problem, are as follows:

| | | |
|---|---|---|
| Hydrogen | (H) — | 1 |
| Carbon | (C) — | 12 |
| Oxygen | (O) — | 16 |
| Sulphur | (S) — | 32 |
| Nitrogen | (N) — | 14 |

In the burning of hydrogen to $H_2O$ (water), it will be seen that 2 atoms of hydrogen, each of weight 1, must combine with 1 atom of oxygen, weight 16; hence, the weight ratio of oxygen to hydrogen is 16 to 2 or 8 to 1, which means that 1 lb. of hydrogen will combine with 8 lb. of oxygen and there results 9 lb. of water. In the same way it will be found that $2\frac{2}{3}$ lb. of oxygen are required to burn 1 lb. of carbon resulting in the production of $3\frac{2}{3}$ lb. of $CO_2$ (carbonic acid gas). When the oxygen needed for combustion is taken from the atmosphere, the nitrogen always present must be taken into consideration. Nitrogen takes no part in the combustion but mingles with the products of combustion, absorbs heat from them and passes away with them. Approximately, it takes 4.25 lb. of air to furnish 1 lb. of oxygen; the remaining 3.25 lb. are nitrogen. When the combustion of the different elements takes place in air, the resulting relative weights are modified on account of the presence of the nitrogen. If then, in the burning of carbon, the oxygen must be taken from the air, it will require 4.25 lb. of air for each pound of the necessary oxygen or $(4\frac{1}{4} \times 2\frac{2}{3}) = 11\frac{1}{3}$ pounds of air will be needed to burn completely 1 lb. of carbon. This process can perhaps be best exhibited by an equation, thus:

1 lb. C + 11.33 lb. Air = 3.67 lb. $CO_2$ + 8.66 lb. N.

In the same way it will be found that for the combustion of 1 lb. marsh gas ($CH_4$), 17 lb. of air are required.

## AMOUNT OF AIR REQUIRED.

It is often convenient to express the amount of air required for combustion in volumes as well as by weight and for convenient reference, both of these values are given in Table 3. These values are only approximate, but for many calculations are entirely satisfactory. It has been assumed that 1 lb. of air at the ordinary temperature and pressure has a volume of 13.1 cu. ft.

TABLE 3. AMOUNT OF AIR REQUIRED TO BURN ONE POUND OF VARIOUS FUELS.

| Kind of fuel. | Carbon | Hydrogen | Sulphur | Marsh gas |
|---|---|---|---|---|
| Weight of Air (lb.).... | 11.33 | 34 | 4.25 | 17 |
| Volume of Air (Cu. ft.). | 150 | 445 | 55 | 220 |

## THE HEAT OF COMBUSTION.

The heat developed by the combustion is absorbed by the products of combustion, and as a result, the temperature of these gases rises tremendously. Thus when carbon is burned in air, the 14,500 B.t.u. developed should heat the 3⅔ lb. of $CO_2$ and 8⅔ lb. of nitrogen from an initial temperature of perhaps 60 deg. fahr. to a calculated final temperature of about 4500 deg. fahr. The actual final temperature, for reasons to be explained presently, is considerably lower. The products of combustion act as a vehicle, carrying the heat developed by combustion to its final destination.

## IDEAL COMBUSTION.

It may be profitable to picture an ideal perfect combustion, and then inquire in what ways actual combustion falls short of the ideal. The given fuel, composed of carbon, various volatile hydrocarbon gases and perhaps sulphur, is to be burned in air. Theoretically, each atom of the fuel finds and seizes upon the number of oxygen atoms with which it will combine. Each carbon atom will meet with two oxygen atoms at a temperature sufficiently high for ignition. They will combine, and the resulting $CO_2$ will pass out of the furnace, carrying with it the heat arising from the combustion; likewise with the hydrogen and sulphur atoms. No more air will be delivered than is just sufficient to furnish the exact number of oxygen atoms, and no carbon or hydrogen atoms will pass out of the furnace without finding oxygen atoms with which they can combine.

## ACTUAL COMBUSTION.

Actual combustion deviates from ideal conditions in many respects. If only the theoretical amount of air is supplied, on account of the

difficulty of properly mingling the fuel and air, some of the fuel atoms will not find oxygen atoms, and will escape uncombined. Again, some of the carbon may burn to carbon monoxide ($CO$) instead of carbon dioxide ($CO_2$), and the $CO$ will escape without further combustion. It is found in practice that to insure complete combustion, an excess of air must be furnished. This excess is usually 50 per cent., and may reach 100 per cent.; i.e., while only 11.3 lb. of air are required for the complete combustion of 1 lb. of carbon, it is usually necessary to furnish 18 to 24 lb. of air. Since the heat of combustion is distributed throughout the excess of air introduced into the furnace as well as the products of combustion, the furnace temperature is lowered by the presence of the extra air.

In another important particular, the actual state of affairs is likely to be quite different from the ideal combustion outlined above. Carbon and oxygen atoms will not unite unless a certain temperature, the ignition temperature, is reached. In parts of the furnace, the temperature may fall below the ignition point because of the inrush of an excess of air, or because of cold bounding surfaces. As a result, carbon particles, even in the presence of plenty of oxygen, will refuse to burn.

## PERFECT COMBUSTION IS SMOKELESS COMBUSTION.

"Any fuel may be burned economically and without smoke if it is mixed with the proper amount of air at a proper temperature."[1]

This is only one of several statements of the so called "Smoke Problem," but it should be borne in mind that perfect combustion is smokeless combustion. This is another reason why the principles of combustion should be carefully studied, so that we may not only eliminate the waste of fuel but also, in a large measure, prevent the smoke which so frequently occurs when we burn our most valuable fuel, bituminous coal.

## COMBUSTION EXPERIMENTS.

A very valuable and interesting set of experiments can be made with an ordinary oil lamp; one with an Argand burner is best. This lamp is designed to burn oil and produce light. It does this very well indeed. It incidentally produces heat. The combustion is very nearly perfect. In this lamp the oil rises by capillarity through the wick. At the top of the burner it meets a supply of air, part of which enters at the bottom of the perforated metal plate on which the chimney rests, the rest at the bottom of the lamp through suitable holes, flowing up through the inside of the round tube which carries the wick. This air supply is

[1] How to burn Illinois Coal without Smoke, Breckenridge. Bulletin 15, Engineering Experiment Station, University of Illinois, Urbana, Illinois.

heated as it flows through the hot metal part of the burner, making it even more suitable for supporting combustion. Here we find ideal conditions for perfect combustion. The fuel flows uniformly and evenly distributed into the furnace at the top of the wick. Air is supplied on each side of the wick which insures a very intimate and perfect mixture with the oil and the oil vapor. The air supply is preheated on its way to the mixing point. The burned gases of combustion are protected from disturbance by the long glass chimney which also serves to draw a continuous supply of air up through the burner as long as the lamp burns.

Experiment with this oil burning furnace:

(a) Turn the lamp up too high. The oil supply is so great that not enough air can reach it and part of the oil escapes unburned. The lamp smokes.

(b) Shut off a part of the air supply at the bottom of the lamp, covering the holes with an old cloth. As the air supply is cut down the flame changes in color and in length; the flame is nearly white at first, then yellow, then red, indicating perfect, fair and poor combustion.

(c) With the lamp turned up about half-way, lower a cold rod of iron into the flame. It cools the flame and even with the correct amount of air, properly mixed, a smoky flame results. Fuel will not burn below a definite temperature, *the temperature of ignition.* A candle and a cold white plate will show this even better.

## CONCLUSION.

Setting free the heat energy which has been so long stored up in coal and converting this energy into the many purposes useful to mankind has been one of the most important developments of the last century. When fuel was plentiful and near at hand little attention was given to using it without waste. Of late much encouraging progress has been made and little by little the application of the simple laws of combustion have been applied to the burning of all fuels. The co-operation of the chemist, the physicist and the engineer has been largely responsible for the progress.

Wasteful methods of burning fuel must stop and we must conserve our rapidly diminishing supply. It is important to observe that all economical devices and methods for burning fuels have finally been successful when provision has been made for supplying the fuel with the *correct amount of air,* properly *mixing* it with the fuel, and *maintaining a high temperature* until combustion has been complete.

The use of fuel is of universal importance; in some form it is used by a large part of our population. Is it not desirable that a knowledge of the simple laws of combustion should be more generally studied and understood?

The subject of combustion is of much importance. Many excellent text books of chemistry and engineering treat the subject completely. It is hoped that this brief and simple presentation of the subject will create a desire to know more about it, so that we may apply our knowledge to the greater conservation of our diminishing supplies.

LECTURE IV.

# SAVING FUEL IN HEATING A HOUSE.

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It is probable that 100,000,000 tons of coal will soon be used yearly in the homes, churches and schools of America, which is at the rate of one ton a year for every inhabitant. The amount of coal required for heating our homes depends largely upon the climate. The long and severe winters of the north require the use of much more coal than is burned farther south.

In this lecture the writer will make use of much material contained in a paper[1] published by the Bureau of Mines in 1915. It should be emphasized at first that in the operation of residence heating equipment the requirements are decidedly different from those encountered in the operation of the furnaces of power plant boilers. In the home we have given great weight to convenience of operation, sometimes at too great a sacrifice of economy. It is evidently time to "save coal in the home", and the continually increasing price which the householder is forced to pay for his supply will make welcome any helpful suggestions toward that end.

The value a householder derives from the fuel he burns depends largely on the character of the heating apparatus, the conditions under which it is installed, and the manner in which the fire is handled. The author, from experience in firing residence-heating apparatus and from observing the methods employed by many who attend to such apparatus, keenly appreciates the importance of proper firing methods, and has written this paper in the belief that some general remarks on the selection, care and operation of residence-heating apparatus may prove of value to many who are interested in burning fuel in the most economical manner. The fuel used in heating homes will be different in different parts of the country. The advantages and disadvantages of the available fuels are well exhibited in Table 1.

## METHODS OF HEATING.

*The Fireplace.*—The first fuel and for centuries the chief one used in residence heating was wood. Heating and cooking operations were often combined, and the old open fireplace with its immense chimney served for both purposes, although in spite of some obvious advantages it was not adopted to produce economically and efficiently the heat needed for either. The need of improved devices was probably more keenly felt in cooking than in heating, and the use of stoves for cooking

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[1] Saving Fuel in Heating a House, by L. P. Breckenridge and S. B. Flagg. Technical Paper 97 Bureau of Mines, Washington, D. C., 1915.

TABLE 1. ADVANTAGES AND DISADVANTAGES OF VARIOUS FUELS AND OF ELECTRICITY.

| Fuel. | Advantages. | Disadvantages. |
|---|---|---|
| Wood | (*a*) Cleanliness, (*b*) cheerful fire, (*c*) quick increase of heat, (*d*) cheap in some localities. | (*a*) Low fuel value, (*b*) large storage space necessary, (*c*) labor in preparation, (*d*) scarcity, (*e*) does not hold fire long, (*f*) unsteady heat. |
| Anthracite | (*a*) Cleanliness, (*b*) easy control of fire, (*c*) easier to realize heat in coal than is the case with other coals, (*d*) steady heat. | (*a*) High price, (*b*) difficulty of obtaining, (*c*) slower response to change of drafts. |
| Bituminous coal | (*a*) Low price, (*b*) availability, (*c*) high heat value (in the best grades), (*d*) low percentage of inert matter (in the best grades). | (*a*) Dirty, (*b*) smoke produced, (*c*) more attention to fire and furnace necessary than with anthracite. |
| Subbituminous coal and lignite. | (*a*) Relatively low price, (*b*) availability (in some regions), (*c*) responds quickly to opening of drafts. | (*a*) Slakes and deteriorates on exposure to air, (*b*) takes fire spontaneously in piles, (c) heat value generally low, (*d*) heat in fuel difficult to realize, (*e*) fires do not keep well, (*f*) gases generated over fire pot sometimes burn in smoke pipe, causing excessive heating. |
| Peat | (*a*) In general, the same as for wood. | (*a*) Low heat value, (*b*) bulkiness. |
| Coke | (*a*) Cleanliness, (*b*) responds quickly to opening of drafts, (*c*) fairly high heat value. | (*a*) Bulkiness, (*b*) liability of fire going out if not properly handled, (*c*) fire requires rather frequent attention unless fire pot is deep. |
| Oil | (*a*) High heat value, (*b*) immediate increase of heat, (*c*) cleanliness, (*d*) small storage space necessary. | (*a*) High price, (*b*) difficulty of safe storage. |
| Gas | (*a*) Ease of control, (*b*) cleanliness, (*c*) convenience, (*d*) immediate increase of heat. | (*a*) High price in many places. |
| Electricity | (*a*) Every advantage | (*a*) High price. |

became quite common while the open fireplace in a modified form was still employed to heat the house.

In any open fireplace, however, close control of the combustion of the fuel is difficult; and large volumes of air not necessary for combustion are, after being heated, carried up the chimney and must be replaced by cold air from outside, which must be heated in turn. One of the most important considerations in utilizing economically any fuel is proper regulation of the volume of air supplied the fire.

*Stoves.*—Stoves were developed for burning not only wood but also coal, oil and gas, although the invention and perfection of more desirable types of heating apparatus served to check the improvement of stoves in this country. In the United States, owing to the comparative abundance and cheapness of fuel, the demand in residence heating has been not only for a higher temperature standard but also for greater convenience of operation and perfection of control. In foreign countries much less use is made of what in this country are considered the best methods and equipment for residence heating, but, on the other hand,

stoves have been more highly developed there. Some foreign stoves, burning what is considered in this country much poorer fuel, offer almost the same perfection of control and ease of operation as the anthracite "base burners" or "self-feeders," formerly so popular.

*Hot Air, Steam, Hot Water.*—The next step toward greater convenience in heating residences was the substitution of one fire in the cellar or basement for separate fires in every room. To convey the heat from the point of generation to the rooms, three general systems have been developed—air, steam, and water heating.

Without entering into any discussion as to the relative merits of the different systems of heating, for which there is insufficient time in these lecture outlines, it has seemed desirable to tabulate again in Table 2 a comparison of the three heating systems, especially pointing out that while the hot air system will be cheaper to install, the hot water or steam vapor system will usually be found to consume the least amount of fuel. Nevertheless, it is true that by careful and correct methods of operation any one of the systems may be operated with a considerable saving of fuel. It should be stated that Table 2 cannot be taken as indicating anything more than the opinion of the writer, whose experience, however, has included the use of each system in his homes in several states, supplemented by a large number of tests of all systems, using wood, coke, anthracite and bituminous coal as fuels.

TABLE 2. FOUR RESIDENCE HEATING SYSTEMS COMPARED.

| System. | Comparative costs. | | Durability | Comfort. |
|---|---|---|---|---|
| | Install. | Operate. | | |
| 1. Hot Air | 50 | 100 | 50 | 60 |
| 2. Steam | 85 | 85 | 90 | 80 |
| 3. Hot Water | 100 | 75 | 100 | 100 |
| 4. Vapor Steam | 90 | 75 | 90 | 100 |

*Cost of Installation.*—Preceding the year 1915 when prices were normal, the cost of installing a good hot water heating system was about $85.00 a room for the average house of 6 to 12 rooms.

*Cost of Operation.*—In the vicinity of New York and Boston where the length of the heating season is about 230 days and the average temperature is from 35 to 40 deg. fahr., the amount of coal burned for heating the average 10-room house when using a hot air system has been about 15 tons, or at the rate of 1.5 tons per room for the season. This estimate does not include coal burned in the kitchen range. It assumes rooms of moderate size and a house that is well built.

*Durability.*—This is a factor of great variation. If the furnace is too small it will have to be operated under conditions which tend to

its rapid deterioration and it will also require more attention. If, on the other hand, the furnace is of suitable capacity there is no reason why a hot water heating boiler should not last for at least twenty years.

*Comfort.*—This is largely a matter of personal opinion, but after experience with all systems the writer has simply expressed his own preferences.

*Ventilation.*—Ventilation should be and may be easily provided with any system of heating. It is obvious, however, that it will require more fuel when cold air is taken from the outside and brought to an inside temperature of 68 deg. fahr. than will be required when the air inside is simply reheated and recirculated. Whatever system of ventilation is adopted it is desirable that suitable provision should be made for its regulation so that it will not be necessary to ventilate rooms which are not being used. It should not be necessary to ventilate all night rooms that are not occupied. A little attention to this will save coal.

## FACTORS GOVERNING CONSUMPTION OF COAL.

There are a number of factors which affect fuel consumption and which are not related in any way to the system of heating or to the kind of fuel used: (a) climate; (b) size of house; (c) type of house, wood, brick or stone; (d) location, exposed or protected; (e) ventilation; (f) size of boiler or furnace; (g) type of furnace—its adaptation to kind of fuel used; (h) chimney—ability to furnish suitable draft (i) care of furnace. These are all factors which must be borne in mind when comparing the coal used for heating different homes. As will be seen, comparisons of residence-heating furnace performance are very difficult to make.

## SAVING FUEL IN EXISTING EQUIPMENT.

While it is desirable to know which heating systems are most economical to install, it is more important to know how to save coal in furnaces and boilers already in use. It is in these furnaces that the coal will be burned in the immediate future. It will also be necessary to refer to some of the different kinds of fuel used in different parts of the country, requiring as they do, somewhat different methods of firing and often special types of furnaces if the fuels are to be burned with satisfactory economy.

*Care of Furnace.*—Unquestionably, with any fuel the prime factor determining fuel consumption and freedom from operating troubles is method of operation. The person most likely to be interested in proper methods of operation is the one who pays the fuel bills, and as a rule, therefore, it is to be expected that better results will be obtained

if the firing is done by the householder than if some one is hired to tend the fires. However, something more than an interest in keeping down the coal bills is necessary; some knowledge of the characteristics of the fuel and of the functions of the different parts of the heater is required to save fuel and trouble.

The furnace of whatever type—air, steam or water—should be kept in good condition. The heat absorbing surfaces should be clean, free from ash or soot. The grate should operate freely. The person tending the furnace should understand just how the grates are intended to operate or much good coal may be lost in the ash-pit. The names of the three dampers for controlling the draft should be known. They are: (a) the ash-pit damper; (b) the smoke-pipe damper; and (c) the check damper.

*Regulation of Draft.*—Many furnaces or boilers are operated in a haphazard way—drafts are opened or coal is put on when the house becomes cool, and then the fire is allowed to burn rapidly until either the rooms are too warm or the fuel is burned down too far to kindle properly a new charge of coal.

Such firing is always wasteful. The heater should receive regular attention, and if the demands for heat are intelligently anticipated, as ordinarily they can be, the house can be warmed with minimum trouble and fuel. When the rooms become too warm the fire should be checked by stopping the admission of air under the grate and decreasing the draft by opening the "check damper." If, as is often done, the draft is reduced by opening the fire door, the combustion of the fuel continues, although at a slower rate, but the cold air entering the fire door chills the heater so that little heat is realized from the coal.

Sometimes the draft is so strong that the difficulty of controlling the fire is increased, especially when the demand for heat is small or the fire is to be banked. To facilitate control under such conditions it is usually advisable to have, besides the check damper, a plain damper in the smoke pipe. During most of the heating season this damper can be kept nearly closed, but during severe weather it can be opened as may be found necessary. Sometimes the draft may be insufficient to burn the necessary quantity of the particular fuel used. If such a condition is always noticed in severe weather, the heater may be too small, the smoke pipe may be choked or poorly fitted to the heater or to the chimney, or the chimney may be too small or be obstructed by soot or debris.

If the draft trouble proves to be due to leaky connections or to obstructions, it can readily be corrected. If the heater or the chimney is too small the difficulties may be lessened either by firing more frequently and keeping the fuel bed thinner, or by using larger coal, of fairly uniform size, in order that the air may more easily flow through

the fuel bed. Conversely, if the draft is very strong, possibly a smaller size of coal may be used to good advantage.

Whatever fuel may be selected, convenience will be promoted by having the heater large enough to maintain for at least eight hours, without attention, proper room temperatures under any weather conditions, except the most severe. If a heater will not do this, it is too small or the draft is insufficient. Satisfactory regulation of the fire will be possible only with a proper equipment of dampers, including (1) a pipe damper in the smoke pipe, (2) a check damper, also in the smoke pipe, and (3) an ash-pit damper (preferably a lift damper) in the ashpit. If bituminous coal is to be burned, a slide or lift damper in the firing door is advisable. This will allow regulation of air supply above the fire, necessary with soft coal. Slight explosions of combustible gas sometimes occur in the furnace after fuel has been put on, and unless the firing door is provided with a lift damper which can be open and relieve the pressure, the door itself may be blown open.

Whether the fuel be hard or soft coal, coke or wood, the pipe damper should be kept partly closed at all times except in severe weather, unless the conditions as to size of boiler and draft are such that all the available draft is regularly needed. In most cases, with the pipe damper partly closed, the proper regulation can be obtained by varying the positions of the check damper and the ash-pit damper. *The fire door should not be used to check the fire* except in emergencies, for the reason that the cold air admitted through the open door cools the fire pot at the same time that it checks the fire.

*Removal of Ashes.*—Usually the most disagreeable feature of tending house-heating apparatus is the removal of the ashes, and the possibility of facilitating the handling of ashes should receive attention when a heater is installed. If the bottom of the ash pit is on a level with the floor or only a short distance below the grates, as is ordinarily the case, ashes must not be allowed to accumulate under the grates for more than two days, or possibly not more than one day, except in moderate weather, and must either be carried from the basement then or stored there and removed later. In any case the ashes must be shoveled at least once with the consequent scattering of dust. A conveniently arranged water connection and a short piece of hose will be found convenient for dampening the ashes before removal. Some heaters are now set with a recess under the base, this recess holding a can into which the ashes drop directly.

## GENERAL SUGGESTIONS FOR FIRING DIFFERENT FUELS.

Fundamentally, the process of combustion is the same for all fuels. Whether the fuel be wood, coal, or oil, heat is produced by the carbon or other combustible elements combining with the oxygen of the air.

The oxygen and these combustible elements unite in certain proportions at certain temperatures and a definite quantity of heat is evolved in each case. Some of the heat is absorbed by other parts of the fuel, heating them to ignition temperature, and some of the heat is absorbed by the nitrogen in the air supplied—ordinary air contains about 80 per cent. nitrogen—and by the gaseous products of combustion, raising them to a high temperature. Part of the heat radiated from the glowing fuel or conveyed by the hot gases passes over the heating surfaces of the boiler or furnace, is taken up by the water or air heated, and is distributed to the rooms of the house.

The admission of more air through the fuel bed or fire door than is required to furnish the oxygen necessary for complete combustion tends to cool the fuel bed and the gases that rise from it. As oxygen unites with combustible elements in definite proportions, the theoretical amount of oxygen and hence of air needed for the complete combustion of a given weight of coal can be computed. See Table 3, Lecture III. However, in burning any kind of fuel on a grate, considerable heat is lost in unburned material if only the quantity of air theoretically required be admitted, because it is practically impossible to get all of the particles of combustible matter in the fuel to unite with all the particles of oxygen in the air theoretically required. An excess of air must always be supplied, but this excess should be neither more nor less than is necessary to insure complete combustion.

The importance of providing an inlet for the air that must enter the furnace room is frequently overlooked, especially in small, tightly-closed furnace rooms. Roughly, 150 to 250 cubic feet of air are required for each pound of coal burned, and, to prevent trouble from insufficient draft, some means for admitting this air to the furnace room must be provided. Usually enough air leaks into the furnace room through cracks and poorly fitted windows, but the tighter the construction of the room the greater the need of an air inlet.

*The flow of air through the fuel makes it burn—learn to control it.*—This is a suggestion of much importance. Try to visualize this *flow of air* through the fuel and you will easily learn how to operate the dampers to control it properly. The feature of controlling the *flow of air through the fuel* is the only thing that requires sense and thought in connection with the economical operation of any furnace. Putting in coal and shaking out the ashes require mostly muscle. It is because we see the coal and ashes that we quickly learn how to manage this part of the operation.

*The Chimney.*—This is a very essential part of the heating equipment. It is the chimney that furnishes the "draft" which draws the air through the fuel bed—whenever the dampers will allow the air to pass. The chimney can draw but very little air through the fuel when the

ash-pit damper is closed, or when the pipe damper is mostly closed. Again, the draft of the chimney is much diminished when by opening the check-damper cold air is allowed to flow directly into the chimney, thus cooling the gases inside the chimney. Again, air must flow *through the fuel* if the fuel is to be burned. The chimney will draw air through all parts of the fuel bed. Thus it is that often we find a good fire on half the grate but still "no heat" being sent up into the house. The fact is we are letting too much air flow through the burned-out fuel and this surplus air cools off the furnace and wastes the coal.

## SPECIFIC AND GENERAL RULES FOR THE OPERATION OF FURNACES.

When in the fall of 1917 it became evident that it would be impossible to produce an amount of coal sufficient to supply the demand, some action became necessary that would, if possible, lead to a universal saving in coal. There immediately appeared many "rules" and "directions," some good, many bad and impossible.

The following two sets of rules were formulated by the writer. Many of the items of these rules have been explained in this lecture. It is essential that careful note should be made of the headings above each set of rules.

### SPECIFIC RULES FOR SAVING COAL IN THE HOME.

(Breckenridge—Lockwood.)

WHAT TO DO....................and................HOW TO DO IT

How to Run

Hot Air Furnaces—Steam Heating Boilers—Hot Water Boilers.

1. *Put your equipment in good order.*
   - (a) See that grates are in good order.
   - (b) Stop air leakes into ash pit or furnace.
   - (c) Cover pipes to prevent unnecessary radiation.
   - (d) Three dampers are necessary: ash pit, smoke pipe, check draft.
   - (e) Learn to use dampers correctly.
   - (f) Control of dampers from room above furnace is desirable.
   - (g) Automatic damper regulation often prevents waste of fuel.
   - (h) KEEP HEATING SURFACES CLEAN; free from soot or dust.

   THE FLOW OF AIR THROUGH THE FUEL MAKES IT BURN—Learn to control it.
2. *Rules for burning hard coal.*
   - (a) Select size giving best control and economy.
   - (b) With strong draft use small sizes.
   - (c) With weak draft use large sizes.
   - (d) Carry a deep fire—at least level with fire door.
   - (e) In mild weather carry a layer of ashes on the grate.
   - (f) Don't shake live coals into ash pit.
   - (g) Save good coal from the ashes.
   - (h) Don't let ashes pile up under the grate.
   - (i) Keep pipe damper partly closed.

(j) Use ash pit and check damper to control fire.
(k) Don't open fire door as a check—it is wasteful.
(l) After the fire is well started put on enough coal to last 8–12 hours.
(m) Burn off gases before closing furnace for night.
(n) To bank fire for night, partly close pipe damper, close ash pit damper, open check draft damper.

3. *Rules for burning soft coal.*

(Notes)
Soft coals vary much more than hard coals.
Many furnaces are not well adapted for soft coal.
Soft coal of uniform size is well adapted for home use.
Soft coal " washed " at the mines is excellent for furnace and stove.
Soft coal requires more attention than hard coal.
(Rules).
(a) Carry a deep fire.
(b) Don't let fire burn too low.
(c) For quick heat put on the draft and fire small amount of coal.
(d) *Pipe damper* should be open when firing fresh coal.
(e) *Pipe damper* should be partly closed when fire is well started.
(f) *Ash pit damper* should be open to start up fire, slightly open during the day, but shut at night.
(g) *Check draft damper* should be shut to start up fire, but open during day and night.
(h) Keep fire door shut.
(i) When fresh coal is fired, admit air over the fire, through slide in fire door.
(j) When firing for a long run, push live coals to one side or back of furnace, then put fresh fuel into hole made. Admit a little air over the fire.
(k) To burn coal slowly (from 4–8 hours) have pipe damper partly closed› adjust check draft and ash pit dampers to give desired rate o burning.
(l) Shake down the ashes when necessary, but don't waste coal in the ash pit. Close ash pit door while shaking.
(m) Don't let ashes pile up under the grate.

4. *To save heat made by burning coal.*

(a) Do not heat *unused rooms.*
(b) Weather strips or storm windows save heat.
(c) Let in sunshine—free heat.
(d) Pull down shades early at night.
(e) Don't ventilate unnecessarily all night.
(f) Don't overheat the house—65 or 70 deg. is sufficient. Get a thermometer.
(g) Watch the weather—don't let the house get too cold.

## GENERAL RULES FOR BURNING COAL IN THE HOME.

(Breckenridge—Lockwood.)

HOW TO RUN

HOT AIR FURNACES—STEAM HEATING BOILERS—HOT WATER BOILERS.

Three things to do: (1) *Put on coal,* (2) *Shake out ashes,* (3) *Control the flow of air through the fuel bed.*

1. *Put on coal.*

(a) A small amount to bring up a low fire and give quick heat.

(b) A larger amount sufficient for long run (8–12 hours).

(When firing soft coal it should not be spread evenly over the surface as is done with hard coal. It is best to push the partly burned soft coal to one side or back of the furnace and fire the fresh coal at the other side or in front. In this way the gases may be burned. Some air above the fire will be necessary.)

2. *Shake out ashes.*

(a) When necessary to make room for more fuel.

(b) To allow the air a freer passage up through the fuel bed.

(Ashes *on the grate* serve as a damper preventing the air from flowing too freely through the fuel bed. They are useful in mild weather. Ashes must not be allowed to pile up under the grates. Don't waste good coal in ashes.)

3. *Control the flow of air through the fuel bed.*

(a) To make coal *burn freely,* " open the draft." This means open ash pit and pipe damper and close check draft damper.

(b) To make coal *burn slowly* (6–12 hours), a good way is partly to close pipe damper, partly open check draft damper and very slightly open the ash pit damper.

(c) To make coal *stop burning,* " shut the draft." This means shut ash pit damper, open check draft damper and very nearly close pipe damper.

4. *Some suggestions of importance.*

(a) Carry a deep fuel bed.

(b) Don't open fire door as a check—it is wasteful.

(c) Keep heating surfaces clean.

(d) Study the operation of your heater.

## USE OF SMALL SIZES OF ANTHRACITE COAL.

When the draft is strong, the use of small sizes of coal is often possible. There may be less advantage now than formerly in burning chestnut size coal instead of stove or egg size because the demand for chestnut has raised the price to practically that of stove or furnace coal. However, in many furnaces, a less amount of the small sizes appears to give the same heating effect.

Fuel bills may be reduced by burning pea size, or better, No. 1 buckwheat, if conditions permit. If the draft is not strong enough, or if the heater is so small that the coal must be burned rapidly, the small sizes may give clinker trouble or may not give heat enough. Under such conditions, it may be necessary to burn the larger sizes of coal exclusively, or at least during the most severe weather.

Householders living where the small sizes of anthracite are used for steam purposes and are generally available can profit most by burning them. In other localities, however, there will usually be a small supply of the fine coal resulting from the breakage of the larger sizes in handling. Some dealers screen out the dust and sell the best of this fine coal under the designation, "yard pea." The price at which it can be ob-

tained will depend, of course, on the demand, but "yard pea" will always cost the householder less than stove, egg, or furnace size.

## FIRING BITUMINOUS COAL.

The wide differences among bituminous coals make it impossible to give more than general suggestions for firing them. However, certain points of difference between the methods of firing these coals and anthracite may be pointed out.

Do not spread fresh fuel over the entire surface of the fire. Bituminous coal requires more air immediately after firing than does anthracite coal or coke, and covering the entire fire not only decreases the flow of air through the fuel bed, but also lowers the temperature in the fire pot enough to cause incomplete combustion of the volatile matter distilled from the coal, and, consequently, a loss of heat up the chimney.

Use some coking method of firing; that is, work the partly burned coal, from which the gas has been driven, to one part of the fire and throw the fresh coal on the remaining portion. The fresh fuel then ignites slowly, the combustible gas is driven off gradually, and the live coals that are exposed on one part of the fire heat this gas and the air coming through the fuel bed, so that more of the gas is burned before it leaves the fire pot. If, on the other hand, fresh coal is spread uniformly over the entire surface of the fire, much of the gas driven off is not ignited, and escapes unburned.

## BANKING THE FIRE WITH BITUMINOUS COAL.

When preparing the fire to last overnight, or for a similar length of time, push some of the burning coal aside, and fire the fresh charge so as to leave a bright spot to ignite the distilled gases. The drafts should then be allowed to stand open for a short period before they are closed for the night, so that the volatile matter, or gases in the coal, may be burned before the air supply is greatly reduced. In adjusting the air supply for the night, use the ash-pit damper and the check damper in the smoke pipe. If the ash pit is tight, the firing door can and should be kept closed, or part of the heat of the fuel will be wasted in heating the cold air entering above the fire. The quantity of fuel that will be required, and the proper adjustment of the draft will vary, of course, with weather conditions, and will have to be learned by experience.

## FIRING COKE.

Coke cannot be burned in the same way as anthracite or bituminous coal, but with proper handling generally can be used with satisfaction

where anthracite can be. In order to have a coke fire last as long and develop as much heat, approximately as many pounds of coke must be fired as of anthracite. The volume of coke, however, will be much greater than that of anthracite, and usually the fire pot will have to be filled completely to hold the fire a considerable period. Coke makes a very porous fuel bed; hence the control of drafts is important. Ordinarily, some ashes can be left on the grate, and they will make draft control easier.

The proper regulation of draft must be learned by experience, in any case, but some general instructions may be given. Before firing a fresh charge, be sure that there is a fair bed of fuel remaining from the last firing, and that it is thoroughly aglow. If necessary, fire a small quantity, and let it become well ignited before putting in the main charge. Let drafts stay on for a short time after the new charge is fired; then they may be checked. Coke of uniform size is desirable, and for small fire pots the coke should be about nut size, whereas for larger fire pots coke of stove or egg size may be satisfactorily used. It may be necessary to have two check dampers put in the smoke pipe in order to control the flow of air through the rather porous bed of coke.

## DATA ON FUEL CONSUMPTION IN A RESIDENCE.

The data here submitted has been furnished the writer by his associate, Prof. E. H. Lockwood. The coal for his 10-room residence has been weighed each year for 3½ years. The heating system is hot water, and the coal used for the season is 10 tons each year. It shows what results may be obtained when an economical system is combined with intelligent methods of operation.

### MEMORANDUM OF COAL BURNED IN A 10-ROOM HOUSE.

(Reported by E. H. Lockwood.[1])

1. *Description*; House at New Haven, Connecticut, Season 1912–13.
   Two stories, plus attic and cellar.
   Frame—with slate roof. Ten rooms heated.
   Windows in good condition with storm windows on north side.
2. *System of heating*; Hot water—direct radiation.
   One cord of wood used a year in fire places.
   (a) Total space heated............. 13,000 cu. ft.
   (b) Total glass surface............. 416 sq. ft.
   (c) Total wall surface............. 1,750 sq. ft.
3. *Kind of fuel used*........................Yard Pea.
   (a) Cost per ton (2000 lb.)..........$4.25
4. *Number of days operated*.................... 219
5. *Total weight of coal burned*................. 9.4 tons.
6. *Cost of coal for season* .....................$40.00
7. *Cost of wood for season*......................$8.00

[1] Complete Report in Technical Paper No. 97, Bureau of Mines, Washington, D. C.

| | | |
|---|---|---|
| | *Temperatures.* | |
| 8. | *Average inside temperature* .................. | 69 deg. fahr. |
| 9. | *Average outside temperature* .................. | 41.5 deg. fahr. |
| 10. | *Average temperature—coldest week* ............ | 20.7 deg. fahr. |
| | *Efficiencies.* | |
| 11. | *Average furnace efficiency* .................... | 65% |
| | (a) Efficiency for coldest week ....... | 67% |

This report shows not only a low cost of heating, but also an economical use of fuel and illustrates what savings may be effected when the problem is given proper consideration. Yard pea could be used because the heater was large enough to burn the coal, even in the coldest weather, at a low rate of combustion per square foot of grate area. Systematic and regular handling of the fire doubtless had considerable to do with the results obtained. The cost of heating is probably $50 to $100 less than what is expended by a large number of householders who live in the same locality and have about the same heating requirements but use more expensive fuel and give their heating equipment less attention.

## LECTURE V.

# BURNING COAL WITH ECONOMY IN BOILER FURNACES BY USING CORRECT EQUIPMENT.

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### MEANS OF ECONOMY.

It is estimated that fully two-thirds of all the coal mined each year in the United States is burned in some kind of a boiler furnace for the purpose of making steam, and that this coal is handled by a quarter of a million firemen. This estimate is doubtless approximately correct. It is because this large amount of coal is handled by such a relatively small number of firemen that every effort should be made to accomplish large savings in the use of these 400,000,000 tons.

In order to bring about large savings in the use of this coal there are two very general and important methods:

1. Provide each boiler with a correct type of furnace or stoker, suitable for burning the coal which is usually available within a reasonably short or economical hauling distance.
2. Adopt correct methods of firing, not only when firing by hand but also when operating approved equipment.

It will be impossible in these lectures to go far into the details pertaining to these two means. Fortunately, there exists to-day a considerable amount of excellent material in books, bulletins and periodicals which will enable the student to secure the desired details. A few references are given at the end of these lectures which should be reviewed and studied.

The present lecture will consider the first method suggested; that of using correct equipment.

### SUITABLE EQUIPMENT.

Any consideration of what constitutes suitable equipment for burning coal for making steam leads us at once to the subject of the steam boiler itself. In the gradual development of the problems of power production, the steam boiler has taken on many forms. These forms have been evolved to fit the use to be made of the boiler. We have accordingly the *stationary* boiler of many forms, the *locomotive* boiler, and the *marine* boiler. In some boilers, the furnace is entirely within the boiler itself, as in the locomotive type, and sometimes it is outside of the boiler, as in most of the stationary types. Depending on the location of the furnace, we speak of boilers as *externally* or *internally* fired. When the furnace is of the external type, there is much more opportunity to adapt

it to the requirements of perfect combustion, and every advantage has been taken of this feature to design furnaces not only of high economy, but also adapted for burning all kinds of coal.

## BOILER DEVELOPMENT.

The early boilers were simple in construction, designed for low pressure, and were not very economical. The long cylinder boiler had the furnace at one end; the gases passed along under one-half the shell, and escaped at a high temperature (often 900 deg. fahr.) into the stack at the other end of the boiler. In this setting, fully 50 per cent. of the fuel was wasted. In order to increase the economy, the gases were returned through flues, placed within the boiler, which cooled the escaping gases to a temperature made lower and lower by the addition of more tubes until a limit was reached in the standard horizontal return tubular boiler—one of the most common of the stationary type. To meet the demand for ever increasing capacity and higher steam pressure, this type of boiler was improved in design and construction until units with pressures of 150 lb. per sq. in. and capacities of 300 horsepower were often installed.

To meet the demand for increase in steam pressure, the shell of the boiler was made thicker, but this made it increasingly difficult to transmit heat through the plates of which the boiler was made.

The demand for increase in capacity was met by adding to the heating surface, which was accomplished by making the boiler of larger diameter, thus making it possible to use a larger number of tubes. But still larger boilers and higher steam pressures were demanded, and to meet the requirements of still greater capacity, safety at higher steam pressures, flexibility of construction and durability under rapid heat transmission, there appeared the water tube boiler.

Boilers of the water tube type have also assumed many shapes and forms. The capacities of single units have grown to 4,000 hp., the pressures are frequently 300 lb. per sq. in. and the efficiency of the boiler and the furnace now often reaches 75 per cent. while even 80 per cent. is not unusual.

## THE BOILER SETTING.

It is often advantageous to consider the boiler setting as made up of several parts: (a) the boiler, (b) the grate, (c) the furnace, (d) the combustion chamber. The *boiler* is the metal structure in which the water is evaporated into steam. It is the function of the boiler to absorb heat produced by burning the fuel. The *grate* is that part of the boiler setting which supports the fuel bed. Through the grate flows a large part of the air necessary for combustion. The grate must be suitable for the coal burned. The *furnace* is the space directly above

the fuel bed, usually extending to the boiler itself. The *combustion chamber*, strictly speaking, includes all the space between the fuel bed and the area at which the gases enter the boiler. Usually, however, it is considered as that part of the space back of the bridge wall. In some boiler units it is difficult to make any distinction between the furnace and the combustion chamber.

Many boiler settings and furnace designs have been put on the market. The different designs have been brought forward to accomplish some special purpose, and in doing this, the designer has frequently neglected other features which should have been given consideration. Again, each manufacturer, having "perfected" his design of boiler, grate or furnace, quite naturally endeavored to push its sale and introduction over a wide territory. Frequently this has been accomplished, but often the results have been unsatisfactory, due to one factor, namely, variation in the kind of coal available. To illustrate, take, for example, the setting of boiler and furnace which has long been known as the "Hartford setting" of a horizontal tubular boiler. This was designed for burning anthracite coal which was plentiful and cheap in the early eighties. It proved to be a very economical combination of boiler and furnace. It was planned for hand firing and high records of economy were obtained with its use. It originated in the east, but its use was extended into the west, where to-day many installations are to be found. This type of setting is very unsuitable for burning the soft coals of the middle-west, and where this setting is used the economy is low, and much smoke is apt to be produced. A properly designed furnace would result in good economy and smoke would be largely prevented.

The same is true of many types of stokers. The chain grate stoker may be operated with high economy and without objectionable smoke when burning the non-caking coals of the middle-west, but all attempts to use this stoker with the caking coals available in the east have been unsatisfactory.

Sufficient has been said to make it clear that economical performance will only be possible when the boiler setting and furnace are suitably designed for burning the coal available.

## VARIATIONS IN COAL.

What is meant by variation in coal should be explained at this point. It will then be possible to point out the important features of the furnace design, to which attention must be given if the coal is to be burned with a satisfactory actual and commercial economy. Variation means: (a) is the coal caking or non-caking? (b) what is the percentage of volatile combustible contained in the coal? To illustrate this, four typical fuels are compared in Table 1.

TABLE 1. VARIATIONS IN SOME TYPICAL COALS.

| | Fixed carbon, per cent. | Volatile matter, per cent. | Moisture, per cent. | Ash, per cent. | Calorific value per pound, B.t.u. |
|---|---|---|---|---|---|
| Anthracite | 86.40 | 3.67 | 3.71 | 6.22 | 13420 |
| Semi-bituminous (Pocahontas) | 75.63 | 19.83 | 0.50 | 4.04 | 14218 |
| Bituminous (Illinois) | 44.14 | 36.35 | 6.66 | 12.85 | 11954 |
| Lignite | 29.55 | 29.28 | 36.13 | 5.04 | 7326 |

In this table it is important to note the *decrease* in the fixed carbon content and the *increase* in the volatile combustible contained in the different fuels. It is important for this reason, that fixed carbon is burned on or near the grates while the volatile matter is burned above the fuel bed in the furnace or combustion chamber.

## CAKING AND NON-CAKING COALS.

Bituminous coals from Pennsylvania and West Virginia are generally caking coals, while those from Ohio and Illinois are non-caking. The former coals present certain difficulties in burning, due to their tendency to stick together in large masses during the early stages of their combustion, and this tendency must be recognized in the design of suitable furnace equipment for burning them, as well as by adapting correct methods of firing when these coals are fired by hand. This variation in coals has made it necessary to design furnace and stoker equipment especially adapted to burning the coals from different districts, and when, for any reason, it becomes necessary to change the character of the coal burned, it may often bring about a very unsatisfactory condition in the boiler room, resulting in a loss of efficiency and capacity.

Furnaces for burning anthracite coal require no special provision for a combustion chamber. This coal contains but a small percentage of volatile combustible, and the fixed carbon, of which it is very largely composed, is burned on or near the grate in the fuel bed itself, so that the grates may be near the heat absorbing plates or tubes of the boiler itself.

No tendency to cake is encountered in burning anthracite coal, and the air required for burning it flows uniformly through the fuel bed when it is kept level. For burning the small sizes, a stronger draft is necessary, and this must be provided by a higher chimney or by using mechanical means for compelling the air to flow through the burning fuel. When a fan is used to push the air through the fuel bed a *forced draft* is provided, and when a fan draws the air through the fuel, an *induced draft*. The demand for anthracite for domestic use has practi-

cally eliminated the coal for use in the making of steam for power purposes, except in the vicinity of the mines, and in a few cities whose laws have thus far prohibited the use of bituminous coal within certain central districts.

## SUITABLE EQUIPMENT FOR BURNING BITUMINOUS COAL.

As has been pointed out already, it is not possible in these lectures to present illustrations showing the many recent developments of furnace and stoker equipments which are proving themselves suitable for burning the different varieties of bituminous coal. It is hoped that the essential features referred to may be shown by lantern slides in most places where these lectures are used. It is important, however, that it should be understood clearly that there exists to-day a large variety of excellent furnaces and stokers which will burn the different kinds of bituminous coal. Moreover, it is essential that careful consideration be given to the availability and character of the coal to be burned before reaching a decision as to the furnace or stoker equipment which shall be installed. If this is done, we shall burn our coal with satisfactory efficiency and also without objectionable smoke, for perfect combustion is also smokeless combustion.

As an aid in the selection of proper furnace equipment it is suggested that attention should be given to the following points:

1. What kind of coal is to be burned? Its heating value, high or low volatile, its ash content, caking or non-caking. Can it be safely stored? Reliability of supply.
2. At what rate will the coal be burned?
3. Will the rate of burning be fairly uniform or will it be subject to sudden and wide variations.
4. What provision is made in the design for burning caking coal successfully?
5. What provision is made in the design for burning the volatile content of the coal, either in a suitable furnace or in the combustion chamber?
6. Has proper provision been made for a correct air supply, properly mixed with the volatile combustible, and all maintained at a sufficiently high temperature until complete combustion has taken place?
7. Are the gas passages so proportioned and the heating surfaces of the boiler so placed that the gasses will be properly cooled before leaving the boiler?
8. Can undesirable air leakage into the setting be prevented? (Excess air is the greatest source of loss.)

If these points are given consideration, suitable furnaces and stokers will be selected, and our coal will be burned with a good economy.

## RATE OF BURNING BITUMINOUS COAL.

When bituminous coal is burned in the hand-fired furnaces of stationary plants it has been found to be good practice to burn it at a rate of from 20 to 26 lb. of coal per hour on each square foot of the grate. This rate will by no means be sufficient in the furnace of a locomotive boiler where the limitations of space and the demand of greater capacity have forced the rate of burning up to 150 lb. and more per square foot of grate area. This high rate is possible because of the high draft available, produced automatically when more steam is used and exhausted through the "exhaust tip" in the smoke box, where the draft produced is frequently equal to 8 in. of water, as compared with the 1 to 1½ in. at the base of tall chimneys.

## LECTURE VI.

# BURNING COAL WITH ECONOMY IN BOILER FURNACES BY USING CORRECT METHODS OF FIRING.

## INTRODUCTION.

In the preceding lecture, the importance of using suitable equipment was discussed; but even when such equipment has been installed the coal will not be burned with good economy unless careful attention is given to correct methods of operation. It is probably true that the largest waste occurs in hand-fired furnaces. It is not as easy to fire bituminous coal with economy as it is to fire anthracite coal. Because of the large number of hand-fired furnaces using bituminous coal it is a matter of great importance that very clear and concise directions should be given for firing such furnaces. Such directions have been prepared by Mr. Henry Kreisinger of the Bureau of Mines and copies of this paper[1] should be secured and distributed in connection with this lecture.

It would be well if a special lecture to stationary engineers and firemen could be given on this topic. The writer has recently given several such lectures and the interest was satisfactory and the attendance encouraging. By co-operating with some local " Branch " or " Engineering Society," much real good may be done in pointing out directly to the man with the shovel the ways and means of saving coal by using correct methods of firing. Fortunately, Mr. Kreisinger's paper is written in a way that appeals to any fireman who is at all willing to help save coal. Over 200,000 copies of this paper have been printed, a fact which indicates its value and popularity.

For the reasons given above the writer feels confident that for the purposes of this lecture he could not do better than to abstract generously some of the leading topics of Mr. Kreisinger's paper. The material selected, while avoiding details, is very important to a clear understanding of the subject under consideration, and points out the reasons why the methods of firing suggested will lead to that very desirable result—the saving of coal.

## GENERAL DIRECTIONS FOR FIRING SOFT COAL.

When burning bituminous coal under power-plant boilers the best results are obtained if the fires are kept level and rather thin. The

[1] Hand Firing Soft Coal under Power-Plant Boilers, Kreisinger. Technical Paper No. 80 Bureau of Mines, Washington, D. C. (Mr. Kreisinger was associated with the writer in the Fuel Tests of the Louisiana Purchase Exposition. He had direct charge of the hand firing of coal for the " 400 steaming tests " made from 1904 to 1906. Since that time he has been continually interested in commercial and actually engaged in research work relating to the burning of bituminous coal).

best thickness of the fires is 4 to 10 in., depending on the character of the coal and the strength of draft. The coal should be fired in small quantities and at short intervals. The fuel bed should be kept level and in good condition by spreading the fresh coal only over the thin places where the coal tends to burn away and leave the grate bare.

Leveling or disturbing the fuel bed in any way should be avoided as much as possible; it means more work for the fireman and is apt to cause the formation of troublesome clinker. Furthermore, while the fireman is leveling the fires a large excess of air enters the furnace, and this excess of air impairs good efficiency.

The ash-pit door should be kept open. A large accumulation of refuse in the ash pit should be avoided, as it may cause an uneven distribution of air under the grate. Whenever a coal shows a tendency to clinker, water should be kept in the ash pit. All regulation of draft should be done with the damper and not with the ash-pit doors.

## COVERING THIN SPOTS.

In firing, the fireman should place the coal on the thin spots of the fuel bed. Thin and thick spots will occur even with the most careful firing, because the coal never burns at a uniform rate over the entire grate area. In places where the air flows freely through the fuel bed the coal burns faster than in places where the flow of air is less. The cause of this variation in the flow of air through the different parts of the fuel bed may be differences in the size of the coal, accumulations of clinker, or the fusing of the coal to a hard crust. Where the coal burns rapidly, the thin places form.

If the firings are too far apart, the coal in the thin spots may burn out entirely, allowing a large excess of air to enter the furnace in streams. If these streams of air are not properly mixed with the gases from the coal, only a small percentage of the air is used for combustion, and most of its passes out of the furnace, depriving the boiler of considerable heat. If, for instance, air enters the furnace at atmospheric temperature, say, 75 deg. fahr., and leaves the boiler at about 575 deg. fahr., it carries away the heat that was absorbed in raising its temperature 500 deg. fahr. This heat is lost to the boiler. Another loss of heat occurs when holes form in the fuel bed, because pieces of unburned coal fall through the grate when the fireman attempts to cover the holes with fresh coal. Therefore, in order to avoid the formation of holes, firings should be made at short intervals, particularly if, for any reason, the fuel bed must be kept thin.

## REASONS FOR SMALL AND FREQUENT FIRINGS.

Soft or bituminous coal should be fired in small quantities at short intervals. The quantities that should be fired vary with the size of the grate and the intensity of the "draft." When the total available draft in the uptake is about 1 in. of water, 2 to 2½ lb. of coal fired per sq. ft. of grate is a fair average. Thus on a grate 8 ft. wide and 6 ft. deep, each firing would average 100 to 125 lb. of coal, or about 6 to 9 shovelfuls. The intervals between the firings should be, on the average, about 5 min. long. In case the draft is high, the periods can be shortened to 3 min.; with a weak draft and sluggish fires the interval may sometimes be lengthened to 8 min., but under ordinary circumstances it should never be longer than 10 min. Small and frequent firings make the coal supply more nearly porportional to the air supply, which in most hand-fired furnaces is nearly constant; they also reduce the formation of crust on the fires and the chance of holes forming in the fuel bed.

With small and frequent firings the fuel supply is at all times nearly proportional to the air supply, so that better combustion is obtained. For the complete combustion of each pound of coal fired, it is necessary to supply about 15 lb. of air. At atmospheric temperature 1 lb. of air occupies a volume of about 13 cu. ft., so that with each pound of coal fired there should be supplied approximately 200 cu. ft. of air. Of this air about one-half is supplied through the grate and fuel bed and one-half through the various openings in and around the fire doors. The air is supplied at a nearly uniform rate.

## AMOUNT OF AIR REQUIRED.

To burn the volatile combustible, about 15 times its weight of air needs to be supplied. Therefore immediately after firing, a large quantity of air should be admitted over the fire and this quantity should be gradually reduced as the distillation of the volatile combustible nears completion. The larger the quantity of fresh coal fired at a time the larger the volume of air needed for the complete combustion of the volatile matter. After distillation is completed only a comparatively small quantity of air need be admitted over the fuel beds.

## RATE OF ADMISSION OF AIR.

It is apparent, then, that the air over the fuel bed should be supplied in variable quantities between each firing, and the total quantity should vary with the weight of coal fired. Such regulation is practically impossible. The openings in the fire-door dampers and other openings, such as those caused by cracked or warped fire doors, may remain the same all the time; so, too, does the draft in the furnace.

Consequently the quantity of air flowing into the furnace over the fuel bed remains nearly the same all the time. Hence it can be easily seen that immediately after firing, when a large amount of volatile combustible is being distilled, the quantity of air entering the space above the fuel bed is not large enough to insure complete combustion. Also, two to five minutes after firing, after the volatile combustible has been driven off, the air supply admitted over the fuel bed may be too large. The only practicable way of meeting these difficulties is by firing the coal in small quantities at short intervals. By this method of firing the distillation of volatile combustible is made nearly uniform and it is at all times nearly proportional to the air supply.

## REGULATION OF DRAFT.[1]

In most boiler plants the load on the boilers varies from hour to hour during the day, and the varying demand for steam is met by burning a varying amount of coal. The weight burned is nearly proportional to the demand for steam. When the demand for steam is high the fireman burns much coal; when the demand is low he burns correspondingly less.

As has been stated the best results are obtained when about 15 lb. of air is used to burn each pound of coal, and it is clear that to burn coal most economically the supply of air must be varied with the rate of combustion. The quantity of air admitted into a furnace should be controlled by the regulation of the draft; that is, high draft should be used with a high rate of combustion, and low draft when a low rate of combustion is desired. Of course, it is impossible for the fireman to obtain high rates of combustion with low draft, but he frequently uses high draft with a low rate of combustion, and by admitting a large quantity of air into the furnace uses 30 or 40 lb. of air, instead of 15 lb., to burn each pound of coal. This large excess of air admitted into the furnace is the greatest source of loss in burning coal under a boiler. The air enters the furnace at atmospheric temperature and passes into the stack at a temperature about 500 deg. fahr. higher. The heat absorbed in raising the temperature of this air 500 deg. fahr. may amount to 30 or 40 per cent. of the total heat in the coal fired. It is, therefore, important to regulate the draft with the rate of combustion.

## THICKNESS OF FUEL BED.

The thickness of fire should vary somewhat with the quality of coal and the available draft. In stationary plants where the available draft in the breeching is about 1 in. of water, and where run-

[1] The significance of draft in steam boiler practice, Ray, Kreisinger, Bulletin 211, Bureau of Mines, Washington, D. C.

of-mine coal is used, the best thickness of fuel bed is 4 to 8 in. In locomotives where the draft in the smoke box frequently exceeds 10 in. of water it is good practice to carry fires 6 to 10 in. thick. Under the usual operating conditions in stationary plants there is no reason why fires should be carried thicker than 8 in. and with some coal even an 8-in. fire is too thick. If the coal is coarse and contains only a small proportion of fine coal, the thickness of the fuel bed may be near 8 in.; but if the coal is mostly small pieces and slack, better results are obtained with the thickness of the fuel bed near 4 in.

## CLINKERING.

Clinker is fused ash, and any coal will form clinker if the ash is heated to the melting temperature. This melting temperature depends on the chemical composition of the ash and on the conditions of heating. The exact effect of each constituent on the melting point of ash is not yet known, but it is certain that the nature of the atmosphere in which the ash is heated has a marked effect on the melting point. If ash be heated in an oxidizing atmosphere (an atmosphere that supplies oxygen) its melting point is higher than if the ash be heated in a reducing atmosphere (an atmosphere that removes oxygen) such as hydrogen or carbon monoxide. The difference between the melting points in an oxidizing and a reducing atmosphere is for some coals over 260 deg. fahr.

*Causes of Clinker.*—Anything that causes the ash to be heated to its fusion temperature causes clinker. The most common causes are thick fire, excessive stirring of fires, burning coal in the ash pit, much slack in the coal, closed ash-pit door, and preheating the air admitted under the grate. The ash of some coals is so fusible that it is difficult to burn the coals without heating the ashes to their fusion temperature. However, with most of the coals mined in the United States troublesome clinker can be avoided by proper care of the fire.

*Remedies for Clinkering.*—To prevent trouble from clinker, find and, if possible, remove the cause of clinker. The following are some general suggestions for avoiding clinker troubles:

Use thin fires and keep the fuel bed level by placing the fresh coal on the thin spots. Avoid leveling the fuel bed with the rake. Above all, do not disturb the fuel bed with a slice bar.

Fire coal in small charges, thus reducing greatly the formation of a crust on the surface of the fires, and the need of breaking this crust. Be especially careful to use small charges if the coal contains much slack.

Avoid burning coal in ash pit. If the ash pit is water-tight keep water in it, if it is not then blow steam under the grate. The steam

can be taken from the exhaust of a feed pump or from any other supply of waste steam. In passing through the ash on the grate and through the fuel bed, the steam is superheated and then partly decomposed into oxygen and hydrogen. The heating and the decomposition of the steam absorb heat. It is thought that this absorption of heat keeps the temperature of the ash below the melting point.

Keep the ash-pit door open. To regulate the draft use the damper in the breeching.

If all of the above rules are observed, under ordinary circumstances and with coal of average quality, there will be no trouble from clinker. In case clinkering continues, relief can be had by spreading a few shovelfuls of crushed limestone over the grate when starting from a banked fire or after cleaning. The limestone should be broken to the size of a walnut.

## COMBUSTION OF BITUMINOUS COAL IN BOILER FURNACES.

*Distillation and burning of the volatile matter.*—When a charge of fresh bituminous coal is spread over the fuel bed in a furnace the coal is heated to about 2,400 deg. fahr. in one to two minutes. This heating distils from the coal the combustible volatile matter which consists of carbon-hydrogen compounds, free hydrogen, and carbon monoxide—last named being incompletely oxidized or burned carbon. Distillation occurs whether any air is supplied to the furnace or not, but to burn this volatile matter completely air must be supplied through the firing door or other special openings. Also, for rapid and complete combustion, the additional air must be intimately mixed with the volatile matter and the mixture kept above the ignition temperature, which is about 1,200 deg. fahr., or a dark red heat. With good mixing the free hydrogen and the carbon monoxide burn very rapidly, but the carbon-hydrogen compounds, particularly the heavy ones, burn more slowly because they contain more combustible substance.

Different kinds of soft coal give off different amounts of volatile combustible on being heated, the proportion varying from 15 per cent. in the Pocahontas type of coal to 45 per cent. in the Illinois type of coal. The volatile matter is mixed with air and burned in the space between the boiler and the fuel bed. The larger the proportion of volatile matter distilled the larger must this space be. Therefore, for burning coals with a high percentage of volatile matter furnaces with large combustion space are needed; also high rates of combustion require larger combustion space than low rates.

*Combustion of the coke.*—The residue left on the grate after the distillation is ended in the so-called fixed carbon. It is mostly in the form of coke and is the chief constituent of the fuel bed. This coke burns completely or partly by coming into contact with the air, supplied

through the grate. The more rapidly air is thus supplied the faster the coke burns, therefore, for a high rate of combustion a large quantity of air must be passed through the fuel bed. Reducing or shutting off the air supply through the grate by carrying a very thick fuel bed, or allowing a solid layer of clinker to accumulate on the grate, greatly hinders and may stop the combustion of the coke; then if the firing be continued only the volatile matter is distilled, and may be burned, while the coke rapidly accumulates in a heap.

Such accumulation of coke on the grate should not be permitted. If the fireman sees that his fire thickens he should reduce the amount of coal fired or increase the flow of air through the grate. He can increase the flow of air by opening wider the damper in the breeching, or, if the damper is already wide open, by lessening the resistance of the fuel bed by freeing it of clinker and thinning the fire.

## BURNING SMOKY COAL WITHOUT SMOKE IN A HAND-FIRED FURNACE.

*Cause of smoke.*—Although these particles of carbon are heated to 2,500 to 3,000 deg. fahr., ordinarily they burn very slowly if the air supply is insufficient or if they are not intimately mixed with the free oxygen of the air. Luminous flame is not carbon in the process of combustion, but particles of solid carbon heated to a high temperature and ready to burn if oxygen is supplied. Usually there is plenty of oxygen in the furnace, but it is supplied in large streams which tend to flow through the combustion space parallel with the stream of combustible or other gas carrying the particles of carbon. Thus the oxygen may not come in contact with the particles of carbon and they leave the furnace and the boiler setting as visible smoke. This carbon would burn if it were intimately mixed with air.

The importance of an intimate mixing of the carbon with the oxygen in the process of combustion can be shown by an experiment in which oxygen is supplied highly concentrated in a solid form. If the soot is mixed with potassium chlorate crystals, one-sixteenth to one thirty-second of an inch in diameter, and the mixture is thrown on a porcelain dish heated to about 850 deg. fahr., there is no evidence of combustion. The potassium chlorate melts and the soot gradually disappears, indicating a very slow oxidation. If, however, the crystals of the chemical are finely powdered and intimately mixed with the soot, the mixture, when thrown on the heated porcelain dish, burns completely with a quick bright flash. The temperature of the dish (850 deg. fahr.) is far below that ordinarily found in a boiler furnace, so that evidently it is the intimate mixing which makes the combustion rapid and complete.

A gasoline engine gives another illustration. In the cylinder of a gas engine an intimate mixture of gasoline vapor and air in the right proportions burns completely with an explosion in spite of the walls of the cylinder being water-cooled. If the same amount of gasoline were injected in a stream into the same amount of air the gasoline would burn slowly with smoke.

Evidently, therefore, visible smoke is much more often caused by lack of adequate mixing than by low temperatures.

The tars constitute about 3 to 15 per cent. by weight of the visible smoke. They are in the liquid or semiliquid form, either as small globules or filling the spaces between the tiny particles of carbon which they seem holding together in clusters. The tar can be separated from the carbon particles by treatment with benzol. In the furnace the tar exists as heavy gases, but in passing through the boiler these cool and condense.

Both the soot and the tar come from the volatile matter of coal. They seem to be formed mostly in the layer of freshly fired coal at the surface of the fuel bed. They pass through the boiler furnace without burning because they do not mix intimately with free oxygen.

*Smoke prevention.*—Visible smoke from a hand-fired furnace can be abated by effecting complete combustion in the furnace of the floating particles of carbon and tar. The conditions necessary for complete combustion are as follows:

1. *Sufficient air supply,* which is somewhat more than the amount necessary for complete oxidation of all combustible matter.
2. *Intimate mixing* of the air with the combustible gases and the floating particles of carbon and tar.
3. *Maintaining a temperature* high enough for the ignition of the combustible while the combustible is mixing with the air.

*Air admission.*—If the fire is level very little free oxygen passes through the fuel bed, although the latter may be only 4 in. thick. With a thicker fuel bed the chances of free oxygen getting through the fuel are still less. Therefore, air must be admitted over the fuel bed in quantities sufficient to burn the combustible gases and the small particles of carbon in the combustion space. This additional air is most commonly admitted through the openings in the firing door, but at some plants is admitted through special openings either above the fire doors or in the dead plate. At still other plants the air is admitted through the bridge wall, and at a few plants a combination of any two or all three methods of admitting air is used. In general, the best method of admitting air is the one that affords the best mixing of the air with the combustible rising from the fuel bed.

As at most plants the admission of air over the fuel bed remains nearly constant all the time, the combustible matter distilled from

the fuel bed should be nearly constant in quantity and quality. This may be closely approximated by small and frequent firings, as already stated.

*Mixing of volatile combustible and air.*—Intimate mixing of the combustible matter with the air does not take place in most hand-fired furnaces, and this lack is perhaps the chief cause of smoky chimneys. In the most common furnace design, where the additional air is admitted through the openings in the fire doors, no mixing-occurs except by the natural diffusion of the gases. As the air and the combustible gas carrying the particles of carbon (soot) in suspension tend to flow in separate streams, combustion takes place only where the two streams are in contact. As the mixing of the two streams is very slow, the combustible matter burns slowly, and some of it escapes unburned, particularly if the combustion space is small.

The same condition exists if the additional air is admitted through special openings in the dead plate or in the front wall above the firing door. If, however, some additional air is admitted through the bridge wall the combustible gas flows between two streams of air so that the mixing is better, and the mixing is still better if the air entering through the bridge wall is forced under pressure through a number of small openings.

At some plants mixing is obtained by special fire-brick structures in the combustion space, such as piers on the bridge wall or in the space beyond the bridge wall, deflecting arches and wing walls. These structures are described and discussed more fully in Bulletins 23[1] and 40[2] of the Bureau of Mines. The chief objection to them seems to be their lack of durability.

Another method of mixing gases and air is by steam jets, which are usually placed in the front wall above the firing doors. The streams of steam cause a whirling motion over the fuel bed and tend to mix the air entering through the fire door with the volatile combustible. The best results seem to be obtained when the air is admitted through small openings around the steam jets instead of through the firing door, for then the steam jets act as injectors, forcing streams of air at high velocity into the combustion space and making the air and the volatile combustible mix intimately. The steam openings in the nozzles should be small and many and should be carefully made so as to utilize the expansion of the steam in producing high velocity. If the nozzles are carefully designed the steam consumption can be reduced to a very small percentage of the total steam made in the

[1] Steaming tests of coals and related investigations, Breckenridge, L. P., Kreisinger, Henry, and Ray, W. T., Bull. 23, Bureau of Mines, Washington, D. C., 1912, 370 pp.

[2] The smokeless combustion of coal in boiler furnaces; Randall, D. T., and Weeks, H. W., Bull. 40, Bureau of Mines, Washington, D. C., 1912, 188 pp.

boiler. The fireman should remember that it is not quantity of steam but high-velocity streams of air that are wanted in the furnace. Steam does not support combustion.

*Maintaining Ignition Temperatures.*—The combustible gases, and particularly the small particles of carbon, must be kept above their ignition temperature until they are mixed with sufficient quantity of air and burned. Cooling before the mixing is completed causes the particles of carbon to pass out through the chimney as black smoke, and some of the combustible gases to condense into tar globules and thus add to the density of the smoke. The light gases, although not visible, may constitute a large heat loss.

In most boiler furnaces the temperature is considerably above the ignition point of the combustible volatile matter. Smoke is usually caused by a lack of mixing, which permits the air and the combustible matter to pass through the furnace in stratified streams.

In boiler furnaces where a large part of the boiler's heating surface is exposed to the fire the burning gases or particles of soot that come in contact with the surface may be cooled below their ignition temperatures and escape unburned or settle on the surface. This is especially true in case the gases move slowly, because slow movement increases their tendency to move in a stratified stream and thus reduces their chance to burn. It should be understood that the visible smoke is not made by the contact of combustible gases with the cool surfaces of the boiler, for the smoke is already in existence as small particles of carbon and tar vapors. The contact merely prevents the combustion by cooling the particles of carbon and the tar vapors below their ignition temperatures.

In some boiler plants the cooling of the smoke-forming particles is prevented by covering the cooling surfaces with fire-clay tile, or by building protective brick arches. Many of these arches serve two purposes—they mix the combustible matter and keep it above its ignition temperature. The arch commonly used in locomotive fire boxes is of value mainly as a mixer.

By proper application of the three principles discussed in the preceding paragraphs it is possible to burn smoky coals in hand-fired furnaces without smoke. However, the conditions under which some commercial plants are operated make such application difficult. Smoky coals are burned without smoke more often in locomotives than in hand-fired stationary plants. One reason for this is that the high draft used in locomotives causes the air to enter the furnace at high velocity, and thus facilitate mixing. Another reason is that locomotive firemen take more care in firing the coal.

## TAKING CARE OF BOILERS.

Power-plant boilers need proper care to give good results. They must be frequently cleaned, inside and out, and kept in good repair.

*Cleaning Tubes.*—All boilers should have the soot blown off the tubes every day when in operation. In addition, fire-tube boilers should have the tubes scraped twice a month, particularly if the fuel is sooty. Blowing out the tubes with steam or air jets removes only the loose particles of soot. A coating of tough soot gradually accumulates in the tubes and not only retards the flow of heat from the hot gases into the boiler water, but also reduces the weight of gases that can be pushed through with a given draft. It is surprising how much the performance of a fire-tube boiler is improved by a good scraping of the boiler tubes.

*Blowing Off and Washing.*—A boiler should be blown off at least once a day, preferably in the morning before starting the day's run. The mud has then settled and can be removed more easily. At the end of the day's run the mud is in suspension in the boiler water and cannot be blown out without running a large part of the water out of the boiler. A boiler should be washed thoroughly on the inside every two to four weeks, the time between washings depending on the quality of feed water. If the water scales the boiler some water-softening compound may be used. Such compound can be best prescribed by a competent chemist after he has analyzed the water. There are a number of substances on the market which in some cases prevent or remove scale. Their merits in each specific case can be determined only by an actual trial. No general rule can be given.

*Stopping Air Leaks in Setting.*—The settings of all boilers should be kept air-tight. Too frequently no attention is given this feature. It is safe to say that on the average fully one-third of the air found in the breeching entered the boiler setting through leaks, and in bad cases twice as much air may enter through leaks as through the regular openings. Leakage is largely responsible for the large chimney losses, and usually occurs through cracks in the walls of the settings or where masonry makes a joint with the metal parts of the boiler. The walls themselves if free from cracks and made of good bricks properly laid in good mortar, are fairly air-tight with the usual pressure difference on the two sides. Cracks in the walls and the openings of joints are caused by difference in expansion due to variations of temperature. They cannot be prevented, but when they form they should be stopped. The best materials for stopping cracks and other leaks are asbsetos rope or packing and asbestos cement. The rope can be purchased in any size. The size needed depends upon the size of the crack or opening to be filled. The rope should be pushed tightly into the crack with a screw-driver or some other blunt-edged tool. If asbestos cement is

used, it should be mixed with very little water, just enough to make the material stick together, and should then be pushed into the cracks or openings like the asbestos rope. After it has dried it shrinks somewhat and may become loose. However, it is so elastic that it can be pushed in farther, closing the crack permanently. A little experience with asbestos cement or rope will give skill in stopping leaks. Lime or cement mortar should never be used; it lacks elasticity and falls out after drying.

Another common source of leaks in small boiler plants is badly fitting ash doors in the rear of the boiler. Some of these doors seem to have no provision made to keep them closed; a brick is set against them to keep them from flying wide open. At some plants the cast-iron frame of the ash door is loose from the wall and allows considerable air to leak in. There may be many leaks in a boiler setting, but those mentioned are typical ones. A good way to find a leak is to hold a candle or a torch to the suspected place, and if there is leakage the flame is drawn in.

All boilers with a brick setting should be frequently examined for leakage, for, as a rule, there is always plenty to be found. Every leak, no matter how insignificant it may appear to be, should be promptly stopped. Time spent in keeping a boiler setting free from leaks is time well spent.

LECTURE VII.

# PERFORMANCE RECORDS AND THE IMPORTANCE OF KEEPING THEM.

## RECORDS ASSIST CONSERVATION.

If any considerable saving of coal is to be accomplished in the operation of boiler furnaces it will be necessary to maintain some systematic plan of keeping records of the performance of the plant. In the past, only the large plants have kept such records, but because of the very large number of small plants that are known to be operated wastefully, the keeping of records must be extended to all plants. The small industrial plants use fully 25 per cent. of coal produced, amounting annually to about 150,000,000 short tons and this coal should not be used wastefully.

The large public utility plants whose product is light, power and heat, have for some years kept very careful records of their daily performance, and since the cost of the coal burned in these plants is often more than one-half the total cost of producing their product, they have made every effort to reduce this cost, and have burned coal and used steam with continually increasing economy. Many of these large public utility plants obtain fully 75 per cent. of the total heat value from the coal used in their boiler furnaces for making steam.

## WHY RECORDS SHOULD BE KEPT.

Unless records are kept, it will be impossible to know whether or not the boiler plant is operating at a good or bad economy. Well-kept records are valuable, and reference to them from month to month, or even from year to year, frequently reveals some unsuspected and wasteful method of operation or shows the value of one kind of coal as compared with another. Where records are kept it gives the fireman a chance to watch the effect of different methods of running; and this of itself will often lead to economy sufficient to repay fully any cost of installing suitable facilities for keeping the records as well as the slight cost of recording the necessary daily observations. When it is known that records are kept, the operating staff begin to take more interest in securing good records.

In many plants a "bonus system" has been successfully used, and such a system can only be introduced where careful records are kept. Instruments of simplicity and precision both for indicating and recording performance are now available in great variety. They are not very expensive and they should be used more generally than at present.

## WHAT RECORDS SHOULD BE KEPT.

In the steam generating plants of the industries which we are now considering, it has not been the custom to any considerable extent to keep records of performance. Such records could easily be kept. In the small plant these records need not be extensive. In the large plant it would pay to keep more records and install more instruments of precision. Suitable "blanks" must be prepared on which the records are to be preserved. Much ingenuity has been exhibited in the arrangement of these blanks so that the important items may be easily figured and suitably placed for future reference. A little care and thought given to the preparation of these blanks will make their use easy when they are needed for later comparisons.

## RECORDS FOR THE SMALL PLANT.

It might be well to classify steam power plants arbitrarily according to their size, and the writer would suggest the following:

| | | | |
|---|---|---|---|
| The small plant.............. | 10 to | 100 | horsepower. |
| The medium plant........... | 100 to | 500 | " |
| The large plant.............. | 500 to | 5,000 | " |
| The commercial plant........ | 5,000 to | 300,000 | " |

Let us first consider the small plant. It is in these plants that we usually find the greatest waste of both coal and steam. Frequently in these plants as much as 10 lb. of coal per hour are used to produce 1 horsepower. This is much too large an amount. There may be conditions of operation which would sometimes justify this large consumption, but such cases need not be many, and the coal consumed to produce 1 horsepower should not exceed 5 lb. per hr. even for the *small plant*. For the *small plant* the following daily records should be kept in connection with the operation of the boiler.

(a) The kind and size of coal used.
(b) The steam pressure.
(c) The temperature of the feed water.
(d) The weight of coal burned.
(e) The weight of water evaporated.
(f) The weight of ash.

In the *medium plant*, in addition to the above records the following should be kept:

(g) The temperature of the escaping gases.
(h) The temperature of the boiler room.
(i) The composition of the escaping gases.
(j) The draft pressure in furnace and base of stack.
(k) The quality of the steam.
(l) The heating value of the coal.

It is, of course, necessary to have the dimensions of boilers and furnaces in order to make the necessary calculations for which these records are kept.

For the *large plant* and for the *commercial plant*, a few additional records are desirable, but for these plants the records as now usually kept are quite complete, and for many plants the records are continuously recorded.

The coal consumption per horsepower per hour in a *medium plant* varies greatly, but it is probable that if a large number of plants were taken as they are running to-day it would be found that at least 5 lb. of coal was used for 1 horsepower, when it ought easily to be possible to reduce this to 3 lb. per hp. per hr.

In the *large plant* and in the *commercial plant* the possibilities for economy increase with the size of the plant. Here the coal consumption per hour should never exceed 3 lb. per hp., should usually be well under 2 lb., and in some plants operating under best conditions the consumption may soon be as low as 1¼ lb. per hp. per hr.

## HOW RECORDS SHOULD BE OBTAINED.

It is not within the scope of this lecture to explain in detail how the above specified records should be obtained. There are available numerous excellent laboratory manuals giving full instructions for the installation and the use of instruments necessary or useful in connection with any plan for keeping records. The titles of a few such manuals are given in the references at the end of this lecture. It should, however, be observed that the records suggested for this small plant are very simple and may easily be obtained; for example, the steam pressure is read from the guage on the boiler, a special thermometer is procurable which may be screwed into a fitting in the feed line, or a mercury well with a simple glass thermometer may easily be arranged for the purpose of reading the temperature of the feed water. The weight of coal and ash will require a pair of scales but a record of wheelbarrow loads properly trimmed off to a known weight is better than no record at all. The weight of water fed to the boiler can best be determined by installing a meter on the feed line. Meters are made for hot or cold water. They are not always accurate, but are easily checked up once or twice a year and for comparative purposes are quite satisfactory. With this simple equipment much valuable information may be obtained. It has been suggested already that consumers of coal must know how it is used, that in the future extreme waste may be prohibited.

## HOW TO USE THE RECORDS.

There are two ways of making good use of the records, these are: (a) compare your results with the best records obtained with similar

equipment elsewhere, (b) compare your daily, weekly or monthly records with each other, with the object of increasing economy or reducing cost of operation. The records should be inspected by some one whose duty it is to look after "waste." If a graphic chart is made from the records, it will often show at once the influence of some unseen leak, the defect of equipment by breakage or improper setting, poor method of operation or change of coal. Corrections may then be made before the "waste" has continued a month or more. Someone in charge of power plant operation must submit a monthly report to the general manager or owner and this report must be given some interest and attention. The fireman must be shown his records from month to month and encouraged to fire in accordance with the best known methods.

## WHAT CONSTITUTES SATISFACTORY ECONOMICAL PERFORMANCE.

Any attempt to reach a conclusion as to what is a satisfactory performance leads to endless discussion. This is natural because of the commercial importance which necessarily must be considered as a part of the problem. When a power plant is manufacturing electrical energy for distribution and sale, the cost of the coal used may constitute 60 per cent. or more of the entire cost of producing its product. If, on the other hand, a power plant is generating 300 horsepower for the manufacture of boots and shoes, it may be found that the cost of coal required for power generation and heating is less than 1 per cent. of the cost of production, so that frequently manufacturers have not given much attention to their power plant operation. When they have given the plant attention it has more frequently been done with a desire to have a fine looking engine room than to obtain any good record of economical performance. It is fair to say, however, that clean engine and boiler rooms lead to economy in the use of coal. It has, nevertheless, seemed desirable to the writer to indicate at least his own opinion as regards what might be called satisfactory economical performance.

The following table is presented with the hope that it may be some indication of what economies may reasonably be expected in the operation of several types of power and heating plant boilers both for the production of steam and the generation of power.

Even better results than those indicated are now frequently found, but it is a fair question if plants should be allowed to operate under conditions which give efficiencies below the low points indicated.

TABLE 1. REASONABLE ECONOMIC PERFORMANCE.
(Stationary steam plants.)

| Type of plant | Efficiency of boiler and furnace. | Coal per hour, pounds. |
|---|---|---|
| | (per cent.) | (per Kw.) |
| 1. Central stations: | | |
| (a) Large 10,000 kw. and up..... | 70–76 | 3–2 |
| (b) Small 2,000–10,000 kw....... | 68–74 | 4–2½ |
| 2. Manufacturing power plants: | | (per i. hp.) |
| (a) Small plants up to 100 hp..... | 60–70 | 8–5 |
| (b) Medium plants 100–500 hp.... | 68–72 | 5–3 |
| (c) Large plants 500–2,000 hp..... | 68–74 | 4–2½ |
| 3. Heating plants: | | (per Boiler hp.) |
| (a) Central 1,000 hp. and up...... | 68–74 | 4–3 |
| (b) Office buildings, public bldgs.. | 50–70 | 6–3 |
| (c) Residences.................. | 50–65 | .... |

## METHODS OF MAKING COMPLETE TESTS OF ANY POWER PLANT EQUIPMENT.

It has for a long time been customary to test boilers, engines, pumps, compressors, turbines, locomotives, in fact every type of prime mover or any kind of steam making or steam using apparatus. At first the tests were rather simple and incomplete, but because of the importance of knowing just what each individual unit would do under varying conditions of operation, these tests grew in complexity, and the methods of reporting them differed widely with engineers, operators and manufacturers.

In order to standardize the form of report submitted by engineers and also to suggest approved methods of testing the different kinds of equipment, the American Society of Mechanical Engineers appointed in 1909 a Power Test Committee. This committee has prepared what is known as the " Power Test Code " of the A. S. M. E. This code was printed in 1915 and is available. It is being revised and extended and will soon be in excellent form for general use for all engineers and manufacturers. It is hoped that all important tests will conform to this code. In this code will be found not only forms and methods but also much detailed information as to the installation and use of the various instruments of precision used in connection with tests of all kinds. All students of engineering should become familiar with this " Code of Rules for conducting Performance Tests of Power Plant Apparatus."

## LECTURE VIII.

# SAVING COAL BY USING WATER POWER.

### OUR DEPENDENCE ON COAL.

The best way to save coal is not to burn it. We have found it necessary to resort to this method of saving during the present winter, 1917–18, much against our wishes. We have also been forced to pay high prices for what we did burn, because coal has often been available only in half- or quarter-ton lots. In the city of New Haven many tons have been sold in paper bags holding but 18 lb. This coal has cost the consumer between $12.00 and $17.00 a ton.

Industries have been closed for lack of coal; churches and schools have been forced to close; all this and much more occurring in a country with abundant coal supplies within short hauling distances from the cities and towns suffering from these privations. But it has served to impress upon every one the great dependence we have placed on coal.

The question has naturally arisen, is there not some substitute for coal? The answer is decidedly, "No." Certainly there is none available in the immediate future. We must continue to use coal for heat, light and power. We must plan at once to produce and distribute over 720,000,000 tons of coal next year with an increasing amount each succeeding year.

### COAL FOR HEAT.

There are, of course, substitutes for coal which can be used for heating, but any possible immediate supply of peat, wood or oil, or all of these combined, would not suffice to replace 12 per cent. of our coal production. We must continue to use coal to produce by far the larger part of our heat.

### COAL FOR POWER.

When we examine the use of coal for producing power we find nearly the same condition. There is, however, one large source of power widely available which may be used effectively to replace a small part of the coal we are now using, namely water.

### WATER FOR POWER.

Water was our first source of power, and in this country, long before coal was mined, water power was developed along our New England

streams. Cities like Holyoke and Lawrence, in Massachusetts, and Manchester, in New Hampshire, have been built up around some of our largest water powers. At first, the mills clustered about the sources of water power. Then came the steam engine, and all that has followed from its development. Next came that far reaching and brilliant helpmate of steam, electricity. What wonders have these two wrought; first, the belted generator, then the connected engine and now the steam turbine. Jealous, perhaps, of the brilliant successes of its competitors, water power is once more fighting for a place besides its old and for a time more successful rival, steam. Water and electricity, working together, can do now what water could not do alone; bring the power and light from the streams and rivers to the cities and towns which need no longer be located at or near the source of power. It can do more. It can collect from many sources power in small units and deliver this collected power in large quantities available for the use of large industries, or minutely subdivided for performing thousands of tasks in the homes of the people.

## WATER POWER AVAILABLE IN THE UNITED STATES.

Frequent attempts have been made to estimate the available water power in the United States, and several years ago the Unite States Geological Survey estimated a minimum potential water power of 36,916,000 hp. with a maximum of 66,518,000 hp., neither figures assuming any plan for storage. This estimate included a minimum of 5,800,000 hp. at Niagara Falls, a maximum of 6,500,000 hp. By international treaty, however, only 25 per cent. of this power can be developed, and only five-fourteenths of the available power belongs to the United States. This means a minimum development at Niagara Falls of only 578,000 hp.

In the "Summary" of a Report[1] published in 1912 the following figures appear:

POTENTIAL WATER POWERS IN THE UNITED STATES, (1912).

| Section of the U. S. | Potential horsepower on a basis of 75 per cent. efficiency. | |
|---|---|---|
| | Minimum. | Assumed maximum. |
| North Atlantic States | 2,225,000 | 4,092,000 |
| South Atlantic States | 2,344,000 | 4,256,000 |
| North Central States | 1,733,000 | 3,558,000 |
| South Central States | 1,438,000 | 2,785,000 |
| Western States | 18,996,000 | 36,707,000 |

[1] Report of the Commissioner of Corporations on Water Power Development in the United States, 1912.

The most significant feature of this tabulation is the figure given for the " Western States." These are the states served by the Rocky Mountains and the ranges near the Pacific Coast. These states have but little coal, and it is here that much important hydro-electric development has taken place. It is here also that we find the development of the " commercial station " whose sole business is to develop, generate, transmit and sell power. These plants have grown rapidly, and they have lead the way in extending their lines over long distances, grouping their plants for economic operation, and in increasing the possibilities of maximum transmission capacity by the use of high voltages. However, in spite of the great growth in waterpower development, which has already taken place, it is estimated that not more than 8 per cent. of the total power in this section has been harnessed.

On the Atlantic coast, a much larger percentage (20–40 per cent.) of the available power has been developed. This is because much less power is available and because the development began much earlier. In this section most of the early plants were built for manufacturing purposes and the power was used by the company owning it.

## WATER POWER DEVELOPED IN THE UNITED STATES.

In the report of the Commissioner of Corporations (1912), already referred to, the following figures are given for the amount of water power developed in the United States.

| Plant. | Horsepower. |
|---|---|
| (a) Small water powers (less than 1000 hp.) | 2,000,000 |
| (b) " Manufacturing " water power | 1,055,000 |
| (c) " Commercial " water power | 2,962,000 |
| Total | 6,017,000 |

This is practically one-sixth of the total horsepower developed in the United States.

In the Proceedings of the Second Pan-American Congress, Section 3, " Conservation of Natural Resources,"[1] several extensive papers were presented relating to the use of water power and from these papers the writer has obtained valuable material. It is not possible, however, to attempt any long discussion of this extremely important phase of power development further than to indicate in a very general way the possibilities of substituting water-made power for coal-made power.

[1] Proceedings of the Second Pan American Scientific Congress, Washington, D. C., 1917. " Hydro-electric Utilization at Niagara and Elsewhere," Maurice Deutsch, pg. 142. " The Combination of Water Resources for Irrigation and Power Development," G. G. Anderson, pg. 297. " The Valuation of Water Powers," W. J. Hagenan, pg. 546. " The Water Power Resources of the United States," M. O. Leighton, pg. 782.

As an indication of present tendencies, it may be well to mention a few of the more important waterpower developments that have been completed within recent years, including also the installations at Niagara Falls.

| Power companies at Niagara Falls. | Installation horsepower. |
|---|---|
| On American side: | |
| Hydraulic Power Co., of Niagara Falls | 144,000 |
| Niagara Falls Power Co | 118,300 |
| On Canadian side: | |
| Ontario Power Co., of Niagara Falls, Ontario | 120,000 |
| Canadian Niagara Power Co | 62,500 |
| Electrical Development Co., of Ontario (limited) | 52,000 |
| International Railway Co | 3,000 |
| Total | 499,800 |

These recent developments only briefly indicated here are more fully described in the Proceedings just mentioned, where also may be found a comprehensive table of the large waterpower plants of the world, originally compiled for the "Electrical World" by Mr. Selby Haar.[1]

The "Salmon River," N. Y., 30,000 hp., under 245-ft. head.
The "Tallulah Falls," Ga., 70,000 hp., under 580-ft. head.
The "Ocoee River," Tenn., one of 27,000 hp. under 110-ft. head. and another 30,000 hp. under 272-ft. head.
The "McCall Ferry," Susquehanna River, ultimate capacity 135,000 hp.
The "Coons River," 13 mi. above Minneapolis, 3,500 hp. under 17½-ft. head.
"Keokuk," Iowa, Mississippi River, present 120,000 hp., ultimate capacity 300,000 hp. under 20–39-ft. head.
The "Pitt River," Mt. Shasta, Redding, Cal., ultimate capacity of 200,000 hp., under 939-ft. head.
The "Klamath River," Thrall, Cal., present 10,000 hp., ultimate, 53,000 hp. Head not given.
"Big Creek," P. L. and P. Co. to Los Angeles, present 60,000 hp., ultimate 400,000 hp., 1900-ft. head, 150,000 volts, 241 mi. transmission.

This will be sufficient to indicate the really large scale upon which already use is being made of water powers. Should the price of coal remain at anywhere near the present (1917) high point, we may look for an extension of existing waterpower plants, and the installation of new ones.

## STEAM AND WATER POWER DEVELOPMENT.

From a chart, "Power Development in the United States," the following figures were taken:

[1] High Voltage Transmission Systems of the World, "Electrical World," April 25, 1914.

POWER DEVELOPMENT IN THE UNITED STATES.

| Year. | Millions of horsepower. | | |
|---|---|---|---|
| | Water. | Steam. | Gas. |
| 1870 | 1.10 | 1.35 | .... |
| 1880 | 1.12 | 2.40 | .... |
| 1890 | 1.25 | 5.00 | .... |
| 1900 | 2.20 | 14.00 | .... |
| 1910 | 5.25 | 23.50 | .... |
| 1920* | (9.00) | (33.00) | 1.0 |

* Extended.

While it is not possible to determine with great accuracy figures such as given above, it is sufficient to indicate the fact that the total power development in the United States is very great, and that the percentage of the total power now being developed from water fortunately is increasing.

## THE ECONOMY OF WATER TURBINES.

The designers and builders of water turbines are to be congratulated on the success which has been achieved in increasing the economy of this prime mover. Ever since 1881, when Mr. Clemens Herschel began the scientific testing of turbines at Holyoke, Massachusetts, the efficiency of the turbine has been going higher and higher, until now, due to care in design, construction and setting, the efficiency of the water turbine is said to have reached 93 per cent. and turbines with such efficiency, combined with generators of even higher efficiencies, leave but little hope of much advancement in the future.

## THE COST OF WATER AND STEAM POWER COMPARED.

The cost of waterpower development is high, especially when it includes the construction of a dam, high-grade electrical generating equipment, and also long distance high-tension transmission lines. There is also a wide variation in this initial cost of plants ranging from \$75 to \$400 per horsepower. An average cost might be taken as close to \$160 per horsepower. It is this high cost of installation that has rendered it more and more difficult to compete with the modern steam turbo-electric plant, for the latter plants have recently been constructed at as low a figure as \$35 per horsepower. This low price of the large steam turbo-electric plant has been brought about by improvements in the design and operation of (a) the steam turbine with its condenser; and (b) the steam boiler with its stoker furnace.

With the price of oil fuel below \$1.50 per barrel in California, large oil-steam-electric plants have been able to compete successfully with

the great hydro-electric plants of that section. With coal below $2.00 a ton in Illinois, some doubts have been expressed as to the possibility of Keokuk power being able to compete with coal-made power in Chicago, near the center of the market for electricity. With coal at or near $4.00 a ton in Connecticut, the cost of water power made in small units has exceeded the cost of coal made power in a modern Hartford steampower plant.

## CO-OPERATION IN POWER PRODUCTION.

Wherever water power is available, it should be used. It will be used more and more, but its greatest opportunity for final success will be when all three elements, water, steam and electricity are brought into a co-operative union. Just as groups of water powers have been united on the Pacific Coast, so must groups of water and steam plants be united on the Atlantic Coast. When coal must be burned for heat in the winter, electricity often could be reclaimed as a by-product. When water is low in the summer months, existing steam plants could often furnish power for electrical energy, thus avoiding the necessity of installing a standby steam plant in connection with every water-power development.

When, to this co-operative combination, is added the possibilty of water storage, we may look forward to some really effective methods of conservation of energy that will save coal.

## PRICES PAID FOR POWER BY THE CONSUMER.

The price at which power is sold to the consumer depends upon several important factors: (a) the cost of producing the power, (b) the cost of distributing the power, (c) the amount of power purchased by the consumer, (d) the amount of power available at any one time for the consumer, (e) the time at which the power must be used, (f) the extent of co-operation between the producers and users of power, (g) the cost of administration.

At Niagara Falls, large quantities of power are sold at $20 per hp. per year, which is about 0.3 of a cent per kw. hour. This power is sold near the falls, and the distributing cost is therefore small.

In Toronto, 90 miles from Niagara Falls, the city buys large blocks of power at $18.50 per horsepower and sells 10-hour power at $28.

In Norway where the great air-nitrate industries consume large amounts of power, the price of power is said to range from $1.90 to $12 per hp. per year.

In this country steam-generated power is made and sold at prices ranging from $30 to $150 per hp. per year for 10-hour power. If the plant capacity is 1000 hp. or over, the cost of power need not be more

than \$25, with the price of coal at \$4.00. The cost will, of course, increase for the smaller plants, but may be as low as \$15 for larger plants (3000 hp.) and coal at \$2.00 a ton.

## FEDERAL AND STATE CONTROL OF WATER POWER.

In an effort to control properly the development of water power, it would seem that, thus far, all legislation had hindered rather than helped its development. The questions involved are complex. They have been carefully considered and fully discussed for the last five or six years. It is important that some very definite policy should be adopted which will equally safeguard the rights of the Federal government, the state and private capital. When this is done, we may look for the more rapid development of many more of our available water powers.

## IRRIGATION AND HYDRO-ELECTRIC POWER.

While the writer has available no facts on the subject of the commercial possibilities of combining irrigation and power, several examples that appeared very promising were observed recently in Southern California. Pumping water electrically to an elevation of 300 or 400 ft., so that it could be used again for power purposes but under a head of 1900 feet, was new to the writer but apparently a perfectly sound engineering procedure; and irrigating land above the "ditches" by pumping or reclaiming arid land in districts beyond the reach of the "canals" but easily accessible by wire and a pumping station, all appeared to indicate possibilities well worth careful consideration.

## THE FUTURE OF WATER AND STEAM POWER.

The development of water power in this country will be gradual. Our coal supplies are vast, and we shall use coal for power production. We shall need 50,000,000 hp. by the year 1930, and of this amount, one-fifth should be water power, or 10,000,000 hp., leaving 40,000,000 hp. to be made by burning coal. This power is probably in excess of our total available potential water power. The writer believes that we might increase our production of power by 12,000,000 hp. without the consumption of any additional coal. To accomplish this, we should expect to assign to water power a development of 4,000,000 hp. This would leave 8,000,000 hp. to be developed by burning coal. It would mean the adoption of more economical equipment on the one hand, and more economical methods of procedure and operation on the other. Some suggestions toward this end are made in the following lecture.

## LECTURE IX.

# THE CONSERVATION OF COAL. HOW MAY IT BE ACCOMPLISHED.

In the preceding lectures, an attempt has been made to discuss briefly some of the important features of the coal problem, and the writer hopes that the discussion may furnish a foundation upon which may be built a structure sufficiently attractive to impress upon the students of science or engineering the importance of assisting in all ways in extending a knowledge of the facts and principles relating to the subject of the conservation of coal, to the end that we may more generally substitute *thrift* for *waste* in the use of one of our most valuable natural resources.

In this last lecture the writer desires to present (a) a series of definite suggestions to which attention should be given if we are determined to prevent the waste of coal, and (b) a few short comments on some phases of the subject which deserve more extended consideration but with which the writer is not sufficiently familiar to warrant discussion in detail.

## HOW TO PREVENT WASTE OF COAL.

1. Extend as rapidly as possible improved methods of mining coal. Under present conditions, one-third the bituminous and one-half the anthracite coal is left in the mine under such conditions that recovery is practically impossible.
2. Extend improved methods of "preparation" of coal at the mines. A premium might well be allowed for well prepared coal, or a penalty imposed for impure coal.
3. Reduce the hazards of coal mining. For every 1,000,000 tons of coal mined, there are between four and five fatalities.
4. Operate the mines a maximum number of days each year. During the last three months of 1917 the operating time lost was fully 28 per cent. This lost time was due to three principal causes, (a) shortage of cars (18.5%), (b) shortage of labor, or strikes (4.5%), (c) mine disability (3.5%).
5. Utilize a larger amount of the mine waste. Briquetted fuel, pulverized fuel and electricity from mine waste; all have been developed successfully.
6. Increase the use of by-product coke ovens. The by-products wasted by beehive cooking are equal to fully 600 lb. of coal per ton of coke produced. The by-products saved in the recent by-product

ovens have sufficient value to pay for the operation of the ovens and the coke might well be considered as the "by-product" instead of the real product.

7. Extend the use of blast furnace gas for power generation. Much progress has recently been made. It will require co-operative effort to utilize fully the power which might be made from blast furnace gas.

8. Extend the use of the gas producer and gas engine for power generation, more especially when electrical energy is not available.

9. Extend waterpower development. Hydro-electric power often combined with steam power offers large possibilities for saving coal. It will require comprehensive expert study before any new development can be undertaken or satisfactory financial returns may not be possible.

(It will be noted that the above nine suggestions relate to savings which are not concerned with burning coal for making steam or heating homes.)

10. Extend very generally the best known performance of locomotives. The better locomotives of 1916 used only two-thirds of the coal required 20 years ago to do the same work. Much saving should be expected in the operation of locomotives. Electrification will save coal where water power is conveniently available. Instructions to firemen should be given even more carefully than in the past.

11. Restrict the supply of coal to power plants operating wastefully. The best coal is often sent to the smaller plants. It is in the small industrial plants (50 to 500 hp.) that the greatest waste occurs. Correct equipment and correct methods combined would save 20 to 25 per cent. of the coal used in these plants.

12. Furnish the homes with correct and simple instructions for operating, with economy, furnace, heating boiler and stove. This involves combining fuel with suitable equipment for burning it. This should result in saving from 10 to 15 per cent. of the domestic coal consumed.

13. Extend electrification. The full use of electricity offers the most promising means of saving coal. Conservation by co-operation through electricity opens up large possibilities.

## A FEW COMMENTS AND QUOTATIONS.

*The gas engine and gas producer.*[1]—The excellent and extensive experimental work of the Bureau of Mines, carried on under the direction of R. H. Fernald during and following the Louisiana Purchase Exposition at St. Louis, served to promote a rapid development of the gas producer. The tests made by the Bureau of Mines showed that all

[1] Engineering oi Power Plants, Fernald and Orrok. McGraw-Hill Book Co., N. Y., 1916.

kinds of bituminous coals could be used in gas producers. They also showed that high economies could be obtained. Lignites and peat were used successfully. If it had not been for the advent of the steam turbine, coming at the same time, the gas engine and producer would have had a still greater and more extensive development; and even now it has many opportunities, especially where cheap electrical power is not available and in those industries where mixed gases are needed for heating processes.

*Waste fuels.*[1]—The economic use of waste fuels is now possible, and special furnaces for burning all kinds of fuels such as sawdust, tanbark, bagasse, culm, coke braize or city wastes have been designed and used successfully. When these "waste" fuels are available, they should be burned. It would be well, however, to secure some expert advice in the matter of furnace design before attempting to burn these fuels.

*Boiler scale.*—A large amount of coal is wasted because of scale deposited on the inside of steam boilers. Not only is coal wasted, but boilers are more rapidly destroyed, and often rendered dangerous because of scale deposits. Fortunately, many steam boilers are regularly inspected by experts of insurance companies organized especially for the purpose, and such boilers are kept reasonably free from scale. If the plant is large, or if the feedwater contains much scale, it is the best plan to remove the scale producing materials from the water before delivering it to the boiler.

*Coal zones.*—The suggestion has been made that coal zones should be established. There are many seemingly apparent advantages in such a plan. It would reduce the haulage distance for much coal. It would determine the general character of coal to be burned within the zone and this should aid in selecting the correct design of furnace or stoker equipment to be used for the various zoned coals. Much coal is wasted because it is now being burned in furnaces not well adapted for burning it.

*Using sun power.*[2]—Low pressure steam engines of from 25 to 100 horsepower have been built and operated by steam generated by the direct heat of the sun. The pressure of steam used was about 1.1 pounds gage and the steam used per b. hp. per hr. was as low as 26.5 pounds, a very excellent performance. John Ericson, the great inventor, writing in 1876 of the problem of solar energy, said:

"Due consideration cannot fail to convince us that the rapid exhaustion of the European coal fields will soon cause great changes with reference to international relations in favour of those countries which are in possession of continuous sun power. Upper Egypt for instance, will, in the course of a few

[1] Factory Power Plants, Myers. The Engineering Magazine, 1915.

[2] The Utilization of Solar Energy. A. S. E. Ackerman. Transactions of the Society of Engineers, London, 1914.

centuries, derive signal advantage and attain a high political position on account of her perpetual sunshine and the consequent command of unlimited motive force. The time will come when Europe must stop her mills for want of coal. Upper Egypt, then, with her never-ceasing sun power, will invite the European manufacturer to remove his machinery and erect his mills on the firm ground along the sides of the alluvial plain of the Nile, where an amount of motive power may be obtained *many times greater than that now employed by all the manufactories of Europe.*"

Dr. S. P. Langley, in his book entitled, " The New Astronomy," says:

" Whoever finds a way to make industrially useful the vast sun power, now wasted on the deserts of North Africa or the shores of the Red Sea, will effect a greater change in Man's affairs than any conqueror in history has done, for he will once more people those waste places with the life that swarmed there in the best days of Carthage and of old Egypt, but under another civilization, where Man shall no longer worship the Sun as a god, but shall have learnt to make it his servant."

It has been estimated that 250 sq. ft. of sunshine area are required to produce 1 horsepower per hour. The ingenuity of man will doubtless be sufficient to perfect suitable power producing equipment using the heat of the sun whenever the diminishing supply of coal begins to indicate such a necessity. Civilization may have to establish itself in the warmer zones and the energy of the sun will have to operate " cooling systems " for our homes.

*Energy direct from coal.*—This is the dream of the scientist and the hope of the engineer. What a wondrous change would be wrought could it be accomplished! The writer once firmly believed that such a discovery would be made long before a heavier-than-air machine would fly. That was because he knew " Darius Green " better than " Old King Coal." Energy, like matter, is never destroyed, it is simply transformed. The energy of the sun, so long shut up in coal, we now need for heat, light or power. When we need it for heat we obtain the heat directly with small loss in the transformation. When we need it for power we must make a series of transformations, each time losing some of the energy.

We usually burn from 3 to 5 lb. of coal per hr. to produce one kilowatt, i.e., 1000 watts. Five pounds of coal contain (5 x 13500) 67500 B.t.u., while 1000 watts is equal to only 3415 B.t.u. This transformation is, therefore, made with a loss of (67500–3415) 64084 B.t.u., or only 5 per cent. of the heat energy in the coal is made available.

If the energy of the coal could be transformed directly into electricity even with a 50 per cent. loss it would immediately effect a saving of nearly half the coal used for making power, and undoubtedly would reduce its cost an even greater per cent. of its present price. But why speculate on what might happen? Our problem is to eliminate waste by all known methods and this we have neglected to do for a long time.

## AVOIDING WASTE OF HEAT, STEAM AND ELECTRICITY.

If we are to use every effort to prevent waste of coal, we must not only prevent waste in its mining, preparation and burning, but we must extend our campaign so as to prevent waste of the product of coal burning, heat, steam and electricity. It is evidently impossible to extend these lectures into this interesting field except to call attention to its importance, and to urge its development and presentation wherever possible.

One suggestion may be made, that the problem of saving fuel should be definitely assigned to some one person in each large industry and that the smaller industries should employ recognized fuel experts to help them with their fuel problems, including heat, light and power.

## CONCLUSION.

In the short time available, it has not been possible to prepare these lectures with the care and completeness which the subject deserves. Much excellent material now exists on this subject in the technical press, in scientific journals and in published books by several well known authors. The writer wishes to acknowledge his indebtedness to many authors freely consulted in the preparation of these lectures. The problem of getting the information at present available into the hands of those who control the burning of coal is a difficult one. It is believed that our scientific and technical schools can be one very important agency in doing this, and it is hoped that these lectures may help stimulate an interest in the subject, and that the future technical graduate will add to his rapidly increasing list of "opportunities for useful public service," that of aiding in the conservation of fuels.

# REFERENCES.

Given below are a few references and sources of information relating to the subjects treated in the lectures. No attempt has been made to make this list comprehensive.

It is evident that the two primary sources of recent investigations concerning American fuels, are: (a) The Bureau of Mines, Washington, D. C., and (b) The Engineering Experiment Station of the University of Illinois, Urbana, Ill. These two institutions have furnished the largest part of the information resulting from fuel research in the country during the last fifteen years. A list of their fuel publications may be obtained on application.

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Bulletin 46.
Tests of a Suction Gas Producer, Garland and Kratz.
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Coal Washing in Illinois, Lincoln.
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Bulletin 79.
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